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EFFECTS OF ANTIMONY, ARSENIC, COPPER AND TIN IN HIGH SPEED TOOL STEEL

By H. J. French and T. G. Digges

Abstract

This paper relates to the effects of added (not residual) antimony, arsenic, copper and tin on low-tungsten high-vanadium high speed tool steel. Hot working and machining properties, hardness after different heat treatments, some metallographic features, and tool performance in both rough turning and finish turning are considered. The magnitude of the effects produced by each of these four elements was dependent upon the type of service to which the tools were subjected. When taking light cuts at fine feeds and high speeds copper produced the smallest decrease on tool life while tin, arsenic and antimony, in order, showed increasingly deleterious effects. Relatively small changes were produced in the roughing tool performance, but each of the four elements tended to affect adversely the hot working properties when present in sufficient proportions in the high speed steel.

Introduction

MODERN high speed steels for cutting tools have been well standardized with respect to the proportions of carbon, manganese, silicon and the important alloying elements, chromium, tungsten, vanadium and cobalt. The effects of variations in one

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A paper presented before the Semi-Annual meeting of the society held in Montreal, Canada, February 16 and 17, 1928. Of the authors, who are members of the society, H. J. French is senior metallurgist and T. G. Digges is assistant scientist, U. S. Bureau of Standards, Washington, D. C. Manuscript received December 29, 1927.

or more of these elements on tool performance and other properties of high speed steels have been the subject of many investigations since Taylor's original work[1]. Much less attention has been given to the effects produced by elements which may be carried into the finished steels from the ores or introduced from the scrap in furnace charges or in other ways.

Individual producers and large consumers have definite views concerning the effects of certain impurities in high speed steels. Such opinions are probably based in part upon practical experience and in part upon experimental observations, but it has been impracticable to secure detailed data on the magnitude of the effects produced or the limiting conditions under which individual elements become important. The need for added information is shown by the fact that the American Society for Testing Materials now has a committee on the effect of tin and arsenic in high speed steels. Requests for comparative data have been received by the Bureau of Standards from different sources, including one steel producer. Accordingly, an investigation which had been in progress for several years[2] was extended to include a study of the effects of elements which are not intentionally added to high speed steels but which may be classed as impurities.

The tests described in this report represent a part of the preliminary work and relate to the effects of antimony, arsenic, copper and tin on the performance of the so-called low-tungsten high-vanadium high speed steel. Other impurities are being considered and tool tests are being made under a wider range of conditions than here reported. Therefore, only tentative conclusions can be drawn but it is hoped that the data presented will bring forth discussion and perhaps also some unpublished results. The low-tungsten high-vanadium type of high speed steel was chosen in place of the more widely used high-tungsten low-vanadium type as previous work had shown it to be more sensitive to manufacturing and heat treatment variables[3]. It was felt that it might also be more sensitive to the impurities under consideration.

[1]On the Art of Cutting Metals, *Transactions*, American Society of Mechanical Engineers, Vol. 28, p. 31.

[2]H. J. French and T. G. Digges: Rough Turning with Particular Reference to the Steel Cut, *Transactions*, American Society of Mechanical Engineers, Vol. 48, p. 533.

[3]H. J. French, Jerome Strauss and T. G. Digges: Effect of Heat Treatment on Lathe Tool Performance and Some Other Properties of High Speed Steels, TRANSACTIONS, American Society for Steel Treating, Vol. 4, p. 353.

Preparation of the Steels and Tools

The steels were melted in an indirect arc furnace, forged and subsequently rolled and tools prepared in the manner already described in detail[4]. Important features of this procedure were as follows.

The molten steel was tapped hot enough to permit its being held in the ladle for a few moments before casting into 55-pound ingots having a top section about 3 by 3 inches and a length of 22 inches. A split iron mold was used in which the ratio of mold weight to ingot weight was about 1.9; in all cases hot-tops were used and a top discard made of about 25 per cent.

The required amounts of metallic antimony, arsenic, copper or tin were placed in the ladle and the molten steel poured on top. After casting, the ingots were allowed to become cold and were then annealed. Surface imperfections were removed on a shaper or surface grinder; the steels containing tin were then forged with a steam drop hammer to ¾ by 1¼ inch bars. All other steels were forged to 2 by 2 inch bars under a press and then rolled into 1½ by 1½ inch bars. All bars were annealed by heating 2 to 3 hours at 1600 to 1650 degrees Fahr. (870 to 900 degrees Cent.) and slowly cooling in the furnace. Forging and rolling temperatures were kept between about 2150 and 1800 degrees Fahr (1175 and 980 degrees Cent.).

Test tools about 5 inches long, with a cross section of ½ by ¼ inch, were machined from the rolled or forged bars. The tools were preheated for 20 minutes at 1600 degrees Fahr. (870 degrees Cent.), then heated to 2350 degrees Fahr. (1290 degrees Cent.) by insertion into a high temperature furnace for 1½ minutes and cooled in a thin oil. They were subsequently tempered 30 to 45 minutes at 1100 degrees Fahr. (595 degrees Cent.) and finally ground to the form and dimensions shown in Fig. 1.

The chemical compositions of the different steels are summarized in Table I, and it will be observed that the proportions of antimony, arsenic, copper and tin are much higher, in most cases, than the proportions which would normally be encountered as impurities in high speed steels. However, it is frequently advantageous to deal with extremes so as to emphasize the effects of important

[4]H. J. French and T. G. Digges: Experiments with Nickel, Tantalum, Cobalt and Molybdenum in High Speed Steels, Transactions, American Society for Steel Treating, Vol. 8, p. 681.

variables. This is the reason for the relatively high proportions of the specified elements in the steels studied.

The effects of residual antimony, etc., may be somewhat different from additions made in the manner described. Elements carried from the ores through ferro-alloys into the steels may be present as different compounds from those formed by additions to molten steels. However, the described tests can properly constitute the first phase of the study of impurities in high speed tool steels.

Spectroscopic examination for antimony, arsenic, aluminum,

Table I

Chemical Compositions of the High Speed Steels Tested

Steel No.	CHEMICAL COMPOSITION—PER CENT C	Mn	P	S	Si	Cr	W	V	Sb	As	Cu	Sn
L(a)	0.71	0.31	0.029	0.026	0.24	3.60	12.75	1.99	....	....	....	....
E97	0.64	0.30	0.006	0.015	0.31	3.41	13.02	1.99	....	....	....	....
S(d)	0.72	0.44	0.037	0.002	0.44	3.52	12.35	1.95	....	....	....	....
E77(f)	0.60	0.28	0.025	0.011	0.14	3.63	12.94	1.81	0.41	....	....	....
E76(e)	0.64	0.50	0.018	0.011	0.33	3.52	13.00	1.89	1.72	....	....	....
E70(f)	0.64	0.25	0.029	0.013	0.16	3.66	13.08	1.78	....	0.09	....	....
E71(f)	0.58	0.32	0.030	0.011	0.13	3.62	12.92	1.79	....	0.78	....	....
E72(e)	0.66	0.24	0.024	0.012	0.18	3.66	13.00	1.94	....	....	0.36	....
E73(e)	0.65	0.31	0.021	0.011	0.18	3.61	13.15	1.92	....	....	0.79	....
E74(e)	0.64	0.26	0.021	0.012	0.19	3.55	12.82	1.92	....	....	1.77	....
E46	0.75	0.27	0.030	0.039	0.19	3.94	12.65	1.99	....	....	....	0.15
E47	0.76	0.25	b	b	0.18	3.98	13.10	1.94	....	....	....	0.57
E48	0.68	0.22	0.020	0.036	0.35	3.97	12.85	2.11	....	....	....	1.20
E49	0.69	0.21	c	c	0.32	3.98	13.10	1.97	....	....	....	1.85

(a)=a commercial high speed steel.
b=not determined; from same molten charge as E46.
c=not determined; from same molten charge as E48.
(d)=A commercial high speed steel used only in the hardness tests.
(e)=These heats from one molten charge.
(f)=These heats from one molten charge.

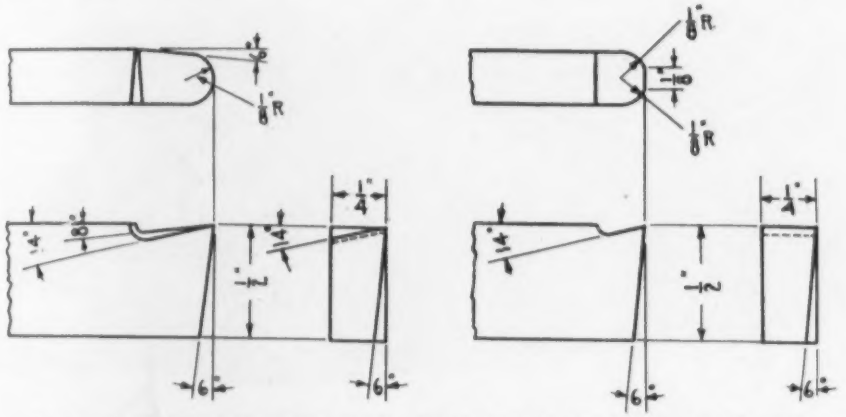
copper and tin was made[5] of the two steels L and E 97, TableI, used as the basis of comparisons. Traces, considered to be about 0.01 per cent and possibly up to 0.03 per cent, of copper and aluminum were found in each steel, but there was no evidence of antimony or arsenic. The most sensitive tin lines are close to iron lines and, therefore, it was difficult to get a positive indication of tin which may likewise be present in traces. In any case, the proportions of these different elements in the steels L and E 97 of Table I are very small and can be neglected in the following discussion.

[5]Examinations made by Dr. W. F. Meggers, chief of the spectroscopy section of the Bureau of Standards.

Methods of Test Employed

The hot-working characteristics of the different steels were observed and the customary hardness tests made after varying heat treatments. Lathe tools were tested under deep cuts and heavy feeds and likewise under light cuts, fine feeds and high speeds.

The rough turning or so-called "lathe breakdown tests" were made in accordance with the procedure used in previous work. This consists in cutting at some selected speed, feed and depth of cut and measuring the time for tool failure which is well defined



Fg. 1.—Form and Dimensions of the Tools Used in the Tests. (Left) Tool for Rough Turning. (Right) Tool for Finish Turning.

and easily recognized. For each steel, four tools were tested after each of two grinds (without intermediate heat treatment) and the average tool life taken as the basis of comparisons. Conversion of these results into the cutting speeds which cause failure in some selected time can be made readily by charts based on Taylor's empirical equations[6].

Test methods for so-called "finishing cuts" are not so well defined and there is not a large foundation of experience or data on which to build. Accordingly, it was necessary first to develop methods of test which would yield reproducible data, but even under such conditions there is not a sufficient background of experience for a complete interpretation of the results.

The method of test employed in the "finish-turning" experiments depends upon the fact that when two tools are set at equal depths in the tool holder the "trailer" or following tool will not cut so long as the "leader" shows no wear. Experience has shown

[6]See footnote (2).

that when the leader has worn about 0.002 inch the trailer begins to cut and this constitutes a more practical criterion than the change in forces measured by dynamometers.

With high speed steel tools under the cutting conditions employed there was a fairly definite transition from the condition in which the trailer did not cut to that in which it did and this corresponded closely to complete ruin of the test tool (leader).

A photograph illustrating the method used in the finish-turn-

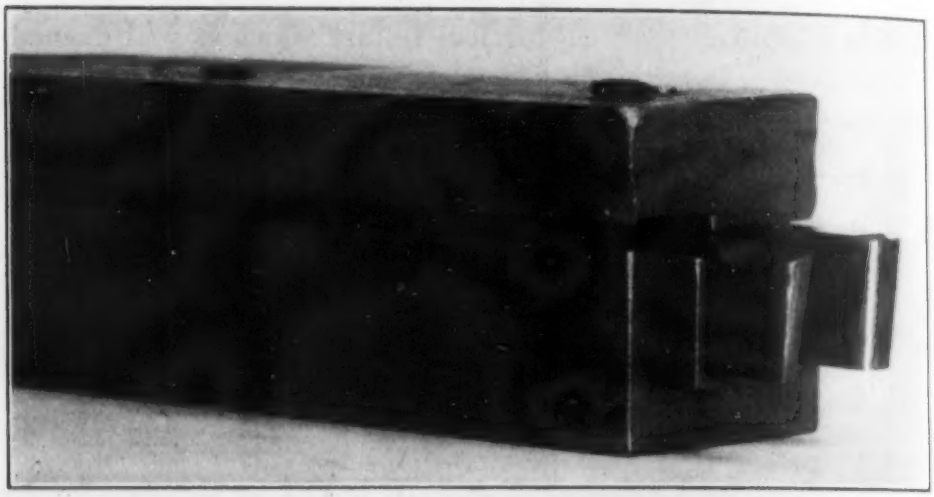


Fig. 2.—Photograph Showing the "Trailer-tool" Method Used in the Finish-turning Tests. The Trailer is Preferably of the Round-nose Type (as illustrated.)

ing tests is reproduced in Fig. 2. Comparisons of the different steels in such tests are based only on the average tool life from ten tests.

In both the rough-turning and finish-turning tests the tools were used in cutting 3.50 per cent nickel steels with tensile strengths around 85,000 to 95,000 pounds per square inch. Details of the chemical compositions and mechanical properties of the test forgings are given in Table II.

Experimental Results

Hot-working and Machining Properties

A summary of the hot-working and machining characteristics of the different steels is given in Table III. Difficulties in hot-working were more pronounced in rolling than in forging or pressing. The steels containing about 1.7 per cent antimony or 1.8 per cent tin showed a high degree of hot-shortness and could not be

Table II

Details of the Test Forgings Used in the Different Tool Tests

Element or Property	TEST LOG NUMBER 36 and 37	40[1]
Carbon, per cent	0.40	0.34
Manganese, per cent	0.74	0.56
Phosphorus, per cent	0.028	0.032
Sulphur, per cent	0.039	0.032
Silicon, per cent	0.24	0.21
Nickel, per cent	3.32	3.30
Proportional limit, pounds per square inch	49,800	42,500
Yield point, pounds per square inch	58,400	48,200
Tensile strength, pounds per square inch	99,200	82,500
Elongation in 2 inches, per cent	24.5	29.0
Reduction of area, per cent	39.8	49.5

[1]Manufacturer's analysis reported.

forged or rolled. None of the other steels gave difficulty in forging but several showed surface cracks on rolling. These were the steels containing 0.4 per cent antimony, the steels with around 0.8 per cent or more of copper and the steels containing 0.8 per cent arsenic.

Table III

Summary of Hot-Working and Machining Properties of Low-Tungsten High-Vanadium High Speed Steels with Additions of Different Elements

Steel No.	Additions	Forging (2150-1800° F.)	Rolling (2150-1800° F.)	Machining of the high speed steel in annealed condition[1]	Remarks
E97	no special addition	O. K.—no cracks	O. K.—no cracks		
E77	0.41% Sb	O. K.	surface cracks		See Fig. 3
E76	1.72% Sb	could not forge or roll—hot short			See Fig. 3
E70	0.09% As	O. K.	O. K.		See Fig. 3
E71	0.78% As	O. K.	surface cracks		See Fig. 3
E72	0.36% Cu	O. K.	O. K.		See Fig. 3
E73	0.79% Cu	O. K.	few surface cracks		See Fig. 3
E74	1.77% Cu	O. K.	few surface cracks	hard to machine	See Fig. 3
E46	0.15% Sn	O. K.			
E47	0.57% Sn	O. K.			
E48	1.20% Sn	O. K.	were not rolled		"smoked" in forging like Mo steels
E49	1.85% Sn	could not forge[2]			

[1]Based on hack-saw, shaper and drill operations.
[2]Difficulties only observed after four or five blows had been struck in both directions with the hammer.

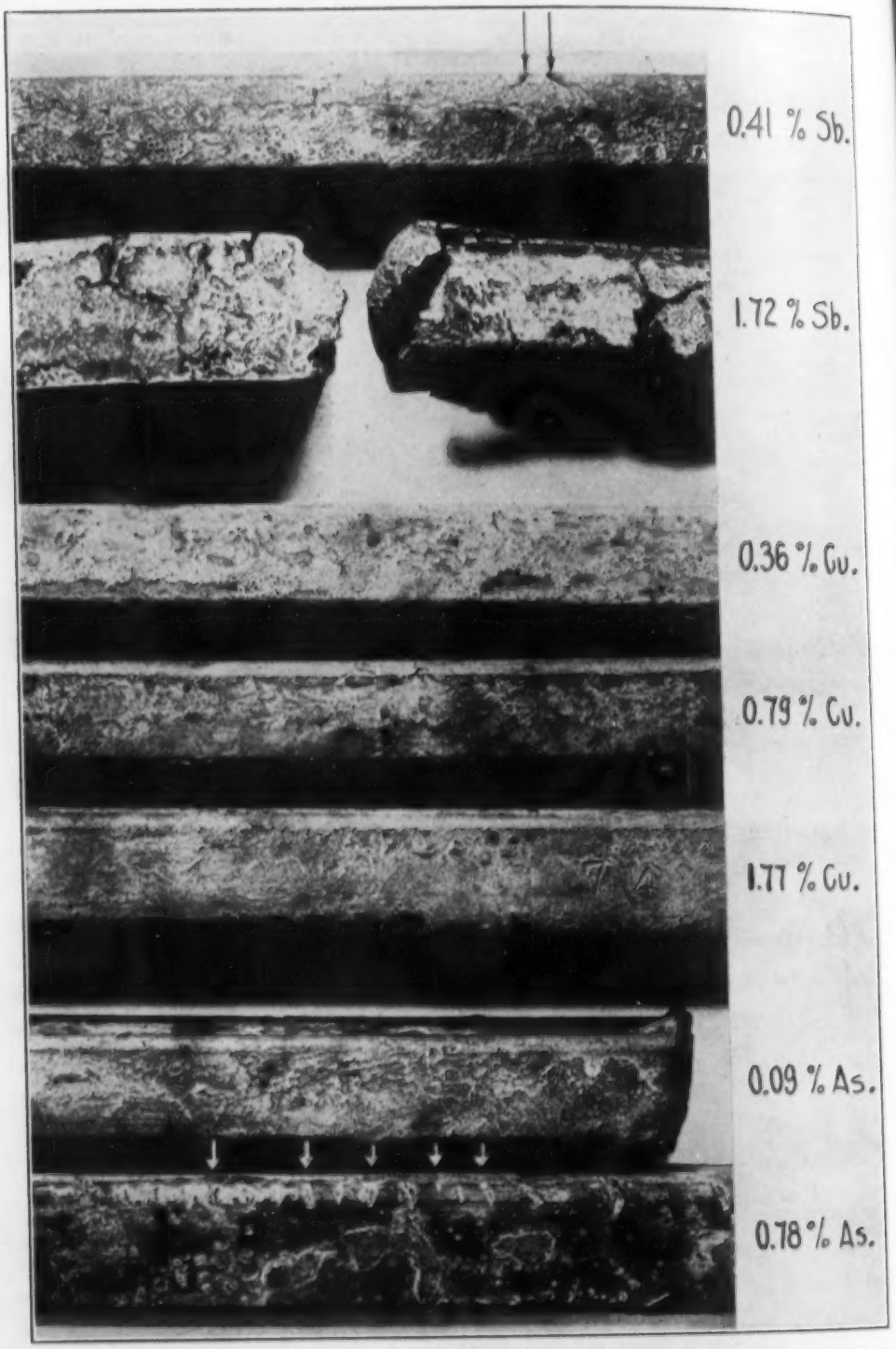


Fig. 3.—Some of the Rolled Bars of High Speed Steels Containing Antimony, Arsenic or Copper. Arrows Point to Some of the Edge Cracks.

Photographs of some of the steels in the rolled condition are grouped in Fig. 3.

Each of the four elements, antimony, arsenic, copper and tin, adversely affected the hot-working properties of the low-tungsten high-vanadium steels. However, several tenths of one per cent or

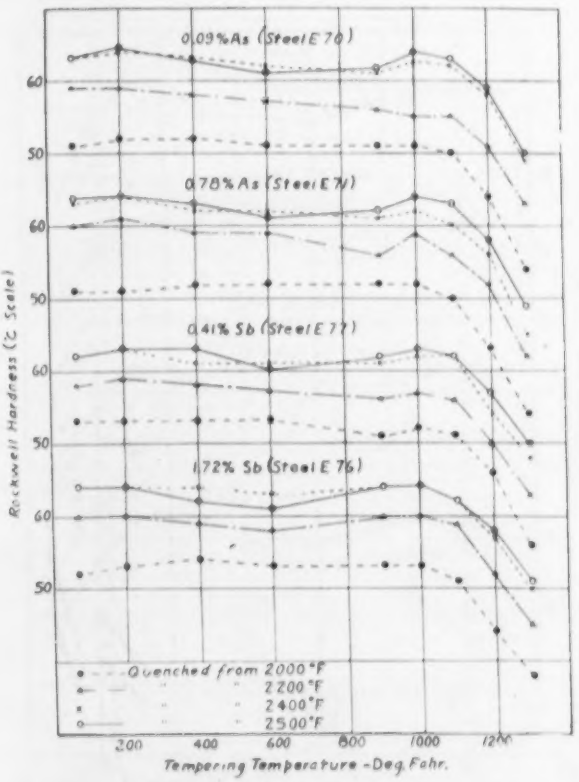


Fig. 4.—Effect of Different Heat Treatments on the Rockwell "C" Hardness of Low-tungsten High-vanadium High Speed Steels, Containing Antimony or Arsenic.

more of each element was necessary before noticeable effects were produced. Only one of the steels was difficult to machine in the annealed condition, namely, that containing about 1.8 per cent copper.

Hardness After Varying Heat Treatments

Rockwell hardness tests were made on samples quenched and tempered in various ways and summaries of the results are given in Figs. 4, 5, and 6.

Antimony, arsenic and copper did not appreciably affect the hardness of the steels within the limits of chemical composition and

heat treatments considered. On the other hand, tin produced some measurable effects. The addition of 0.15 per cent tin increased the hardness of the steel as oil-quenched from 2000 degrees Fahr. (1095 degrees Cent.); when the proportion of tin was raised to 0.57 per cent there was an additional increase in the hardness but with further increase in the tin content the hardness decreased. (Fig. 6).

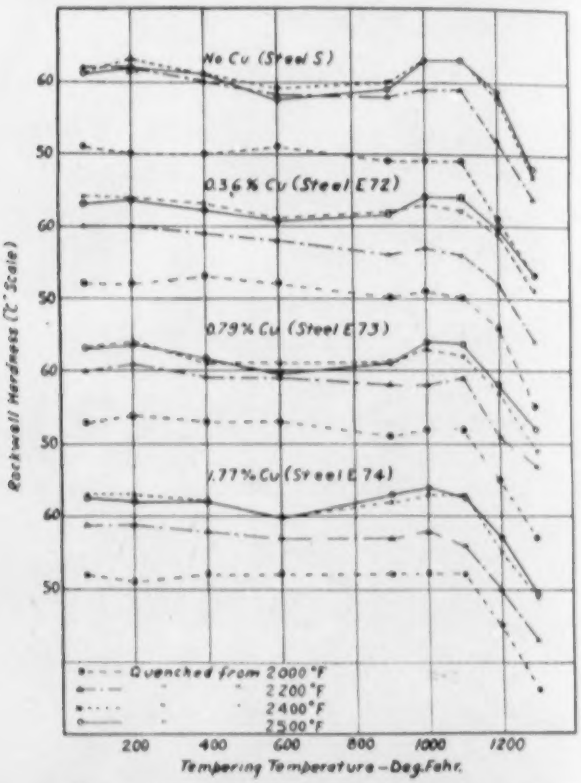


Fig. 5.—Effect of Different Heat Treatments on the Rockwell "C" Hardness of Low-tungsten High-vanadium High Speed Steels, Containing Copper.

No such differences were observed when the steels were quenched from higher temperatures; likewise, the maximum hardness obtained on tempering was practically the same in all cases.

Metallographic Features

Preliminary metallographic examinations were made, as illustrated in Figs. 7, 8, and 9. It should be kept in mind, in examining these photomicrographs, that comparatively small variations in time and temperature in the high temperature treatment may produce noticeable differences in the microstructural features of high speed

steels and that these alloys seldom show entire homogeneity. The photomicrographs reproduced in Figs. 7, 8, and 9 were selected to represent average conditions and show some definite changes resulting from the additions of antimony, arsenic, copper and tin.

The microstructure of a commercial steel (L, Table I) is in-

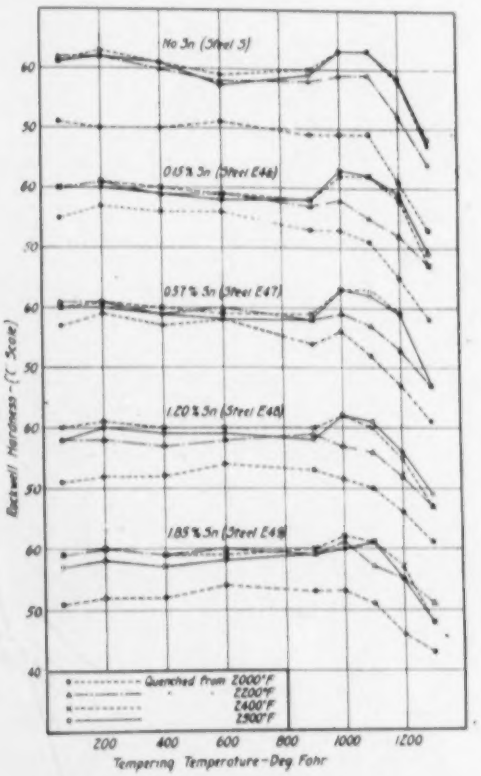


Fig. 6.—Effect of Different Heat Treatments on the Rockwell "C" Hardness of Low-tungsten High-vanadium High Speed Steels Containing Tin.

cluded in each of the Figs. 7, 8, and 9, for general comparisons and is compared to the corresponding experimental steel (E 97, Table 1) in Fig. 9. It will be observed that the smallest additions of antimony, arsenic, copper or tin have produced no very definite changes in grain size of samples oil-quenched from 2350 degrees Fahr (1290 degrees Cent.). As the proportion of copper is increased the grain size tends to become larger while with increase in antimony, arsenic, or tin the grains tend to become smaller.

It is, perhaps, important to note that there is a uniform distribution of the "hard constituents" (tungstides, carbides, etc.)

Table IV
Summary of the Results of Finishing-Turning Tests ("Follower-Tool" Method)

Steel No.	Type Composition—per cent C	Cr	W	V	special elements	Cutting Conditions: test log No.	speed ft./min.	feed in./rev.	depth of cut inch	Tool Life, minutes: 1	2	3	4	5	6	7	8	9	10	Ave.
L	0.71	3.60	12.75	1.99	.....	40	400	0.0115	0.010	...	...	78.9	32.1	52.1	29.5	47.9	24.8	53.8	45.2	45.5
E47	0.76	3.98	13.16	1.94	Sn 0.57					31.5	34.0	43.3	20.9	59.3	28.6	25.0	45.8	17.7	34.5	34.1
E49	0.69	3.98	13.10	1.97	Sn 1.85					18.4	38.5	7.7	4.5	13.3	25.4	24.3	15.9	10.6	12.3	17.1
E71	0.58	3.62	12.92	1.79	As 0.78					27.7	23.2	41.0	18.1	8.4	6.7	13.2	6.5	12.4	13.4	17.1
E77	0.60	3.63	12.94	1.81	Sb 0.41					15.2	23.5	27.5	37.7	24.7	24.5	35.5	13.6	10.1	6.9	21.9
E74	0.64	3.55	12.82	1.92	Cu 1.77					64.0	32.4	41.4	44.5	16.8	24.0	22.5	14.1	37.8	18.6	31.6
L	0.71	3.60	12.75	1.99	.....	40	400	0.0154	0.005	86.1	68.1	92.3	76.3	63.7	42.6	51.7	50.3	51.4	51.8	63.4[1]
E70	0.64	3.66	13.08	1.78	As 0.09					69.8	92.5	63.3	31.8	52.9	51.2	45.5	45.7	60.3	41.9	55.5
E71	0.58	3.62	12.92	1.79	As 0.78					30.8	46.0	20.7	44.2	40.9	27.2	34.4	28.7	9.4	28.2	31.0
L	0.71	3.60	12.75	1.99	.....	40	400	0.0154	0.005	65.4	32.8	48.3	53.6	45.5	35.0	39.3	38.0	46.3	66.6	47.1[1]
E97	0.64	3.41	13.02	1.99	.....					58.2	43.9	45.7	51.4	40.7	57.4	46.3	36.9	51.1	56.6	48.8

All tools preheated for 20 minutes at 1600 degrees Fahr. (870 degrees Cent.), heated for 1½ minutes at 2350 degrees Fahr. (1290 degrees Cent.), quenched in oil and tempered for 30 minutes at 1100 degrees Fahr. (595 degrees Cent.). Tool form shown in Fig. 1.

[1]Each group in the above table represents an independent set of tests. The difference in tool life of steel L in the second and third sets of tests made under the same speed, feed and depth of cut is probably due in large part to variations in the cutting properties of the test forging. Tools in the third group of tests were cutting at a smaller diameter than tools in the second group.

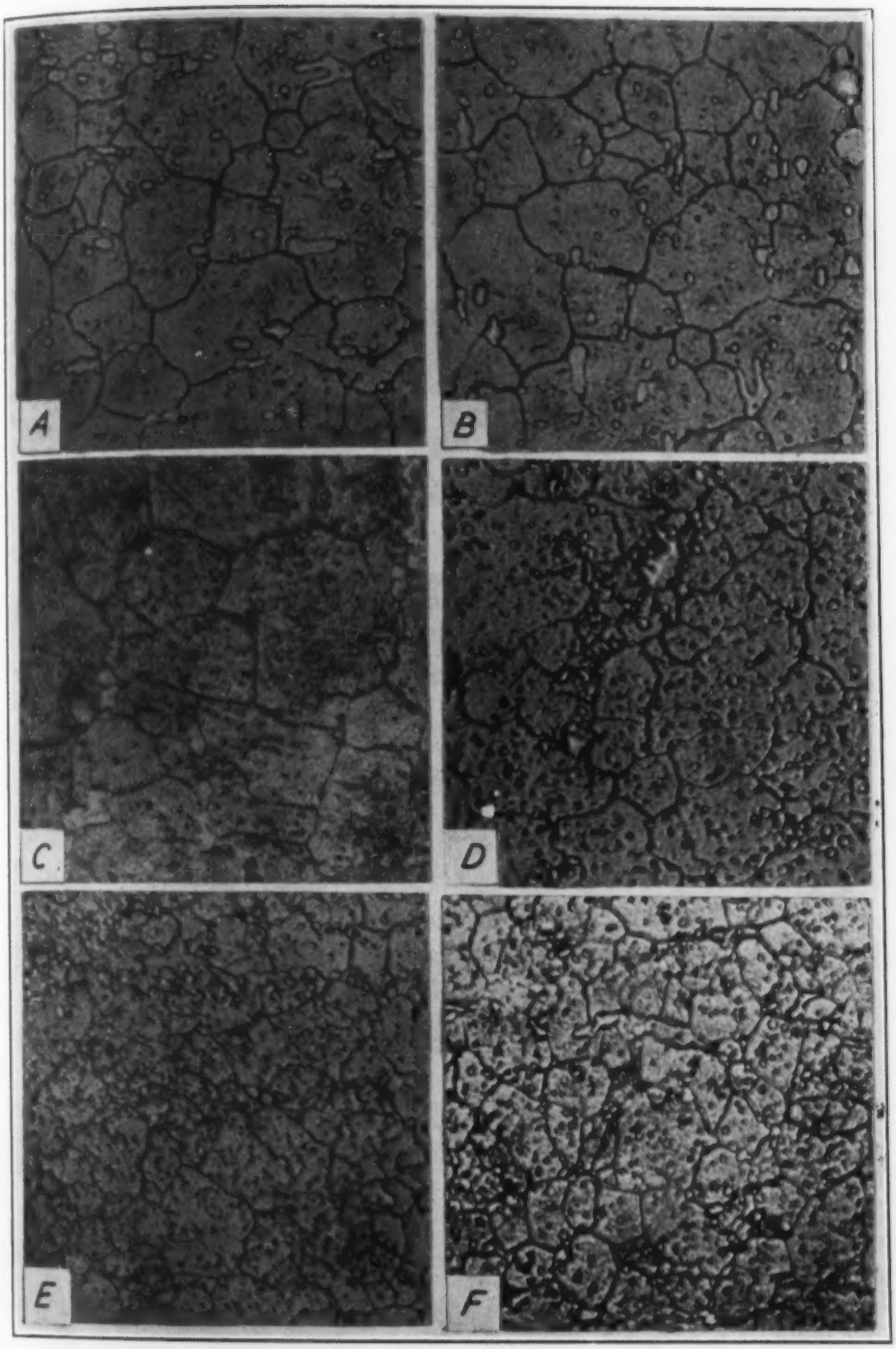


Fig. 7.—Microstructure of Low-tungsten High-vanadium High Speed Steels Containing Different Proportions of Arsenic or Antimony. Samples Oil-quenched from 2350 degrees Fahr., not tempered. Etched with 2 per cent Nitric Acid in Alcohol. Magnification 750x. A—Steel L No Arsenic. C—Steel E70, 0.09 Per Cent Arsenic. E—Steel E71, 0.78 Per Cent Arsenic. B—Steel L No Antimony. D—Steel E77, 0.41 Per Cent Antimony. F—Steel E76, 1.72 Per Cent Antimony.

in all of these experimental melts and no signs of "stringers" or other segregations frequently observed in high speed tool steels.

Tool Tests

The results of the rough-turning tests and the first set of finish-turning tests (see Table IV) are summarized in Fig. 10. In each

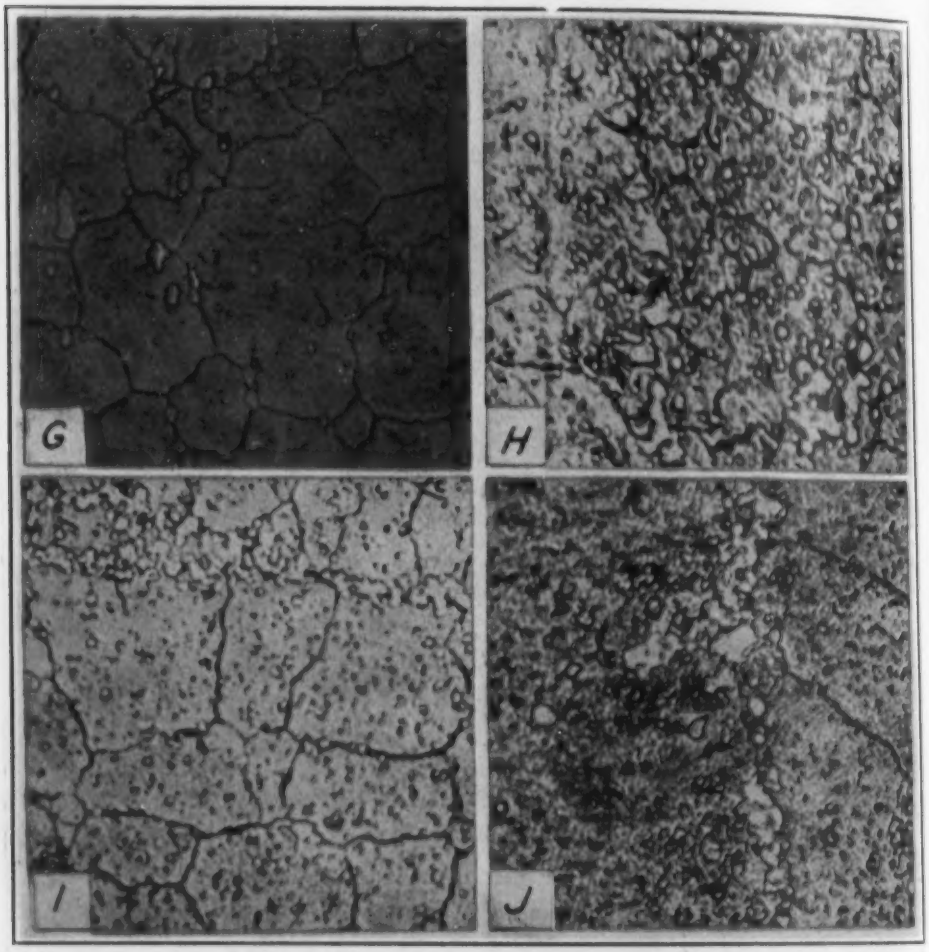


Fig. 8.—Microstructure of Low-tungsten High-vanadium High Speed Steels Containing Different Proportions of Copper. Samples Oil-quenched from 2350 degrees Fahr., Not Tempered. Etched with 2 per cent Nitric Acid in Alcohol. Magnification 750x. G—Steel L No Copper. H—Steel E72, 0.36 Per Cent Copper. I—Steel E73, 0.79 Per Cent Copper. J—Steel E74, 1.74 Per Cent Copper.

set of tests the tools were tested in sequence to minimize performance variations caused by inhomogeneities in the steels cut. This applies to rough turning and to finish turning and consists in first

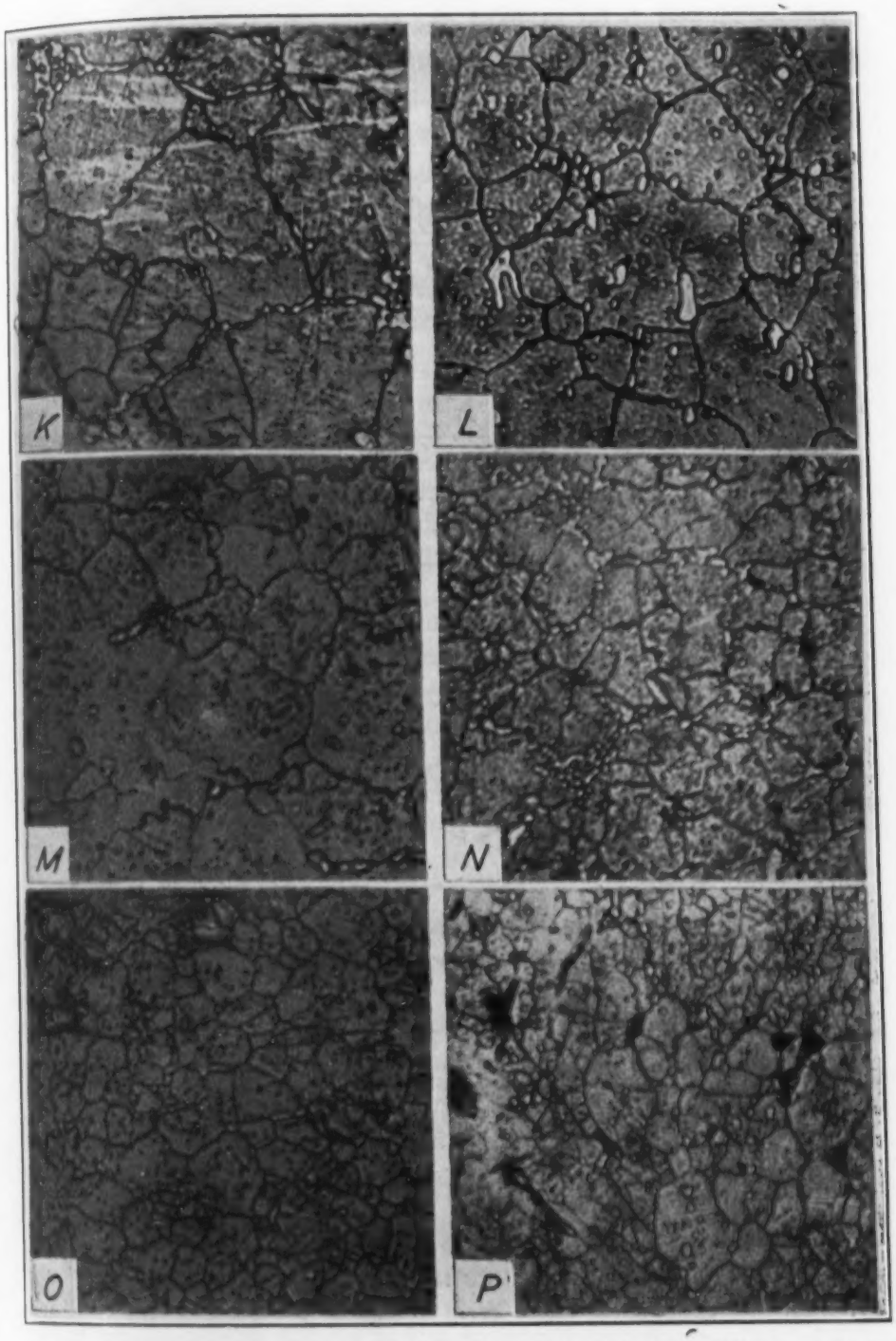


Fig. 9.—Microstructure of Low-tungsten High-vanadium High Speed Steels Containing Different Proportions of Tin. Samples Oil-quenched from 2350 degrees Fahr., Not Tempered. Etched with 2 Per Cent Nitric Acid in Alcohol. Magnification 750x. K—Steel E97, No Tin. L—Steel L No Tin. M—Steel E46, 0.15 Per Cent Tin. N—Steel E47, 0.57 Per Cent Tin. O—Steel E48, 1.20 Per Cent Tin. P—Steel E49, 1.85 Per Cent Tin.

testing one tool from each of the steels which are to be compared and then testing in order the second tool from each steel, etc.

Comparisons in rough turning are based on the average values from four tools tested after each of two grinds. "Taylor speed"

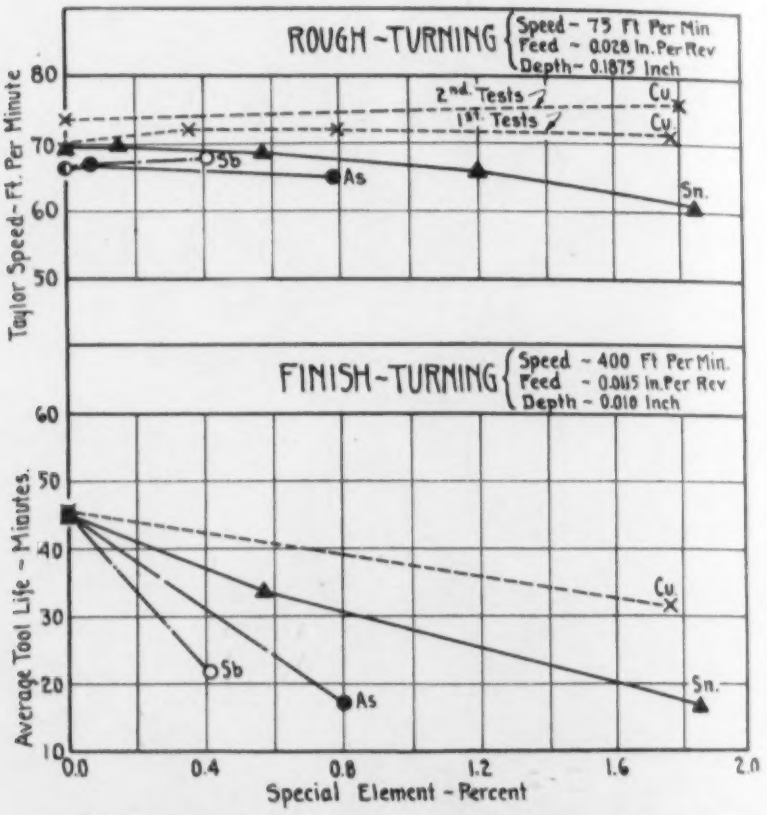


Fig. 10.—Effects of Antimony, Arsenic, Copper and Tin in High Speed Steels on the Taylor Speed in Rough Turning and on the Tool Life in Finish Turning.

Tests were Made Without Cutting Compounds under the Conditions Stated in the Body of the Chart. Tool Forms are Shown in Fig. 1.

which represents the speed which causes tool failure in exactly twenty minutes, was computed from the results of the life tests and the empirical equation, $VT^{\frac{1}{7}}=C$, in which V is the cutting speed, T is the tool life, and C is a constant.

Comparisons in finish turning are based on the average tool life from ten tests of each steel. Since a new test method was used for these light cuts at high speeds, a tabular summary is also given in Table IV to show the extent of the variations in individual tools. In most cases these were no greater than the variations

encountered in the customary rough-turning tests and the averages used for comparisons are consistent among themselves. However, only large differences should be considered just as in the case of the rough-turning tests.

The steels containing different proportions of antimony, arsenic, copper and tin are compared with a commercial high speed steel. However, this steel was found to have practically identical performance in either rough turning or finish turning with experi-

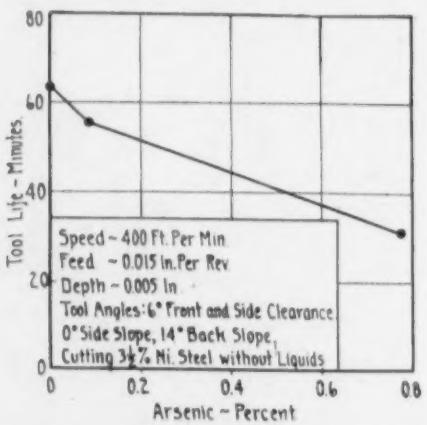


Fig. 11.—Effect of Arsenic on the Performance of Low-tungsten High-vanadium High Speed Steels in Finish Turning.

mental steels of like composition. Some comparisons in rough turning have already been given in a previous report[7] while those in finish turning are included in Table IV. Under such conditions the described tests show the effects of the different impurities and also the relation of these effects to the performance of commercial high speed tool steel.

As shown in Fig. 10, the changes in tool performance produced by additions of antimony, arsenic or copper to high speed steel were relatively small in rough turning. Such differences as exist in the numerical values of the Taylor speed are within the limits of reproducibility in lathe breakdown tests, although in two independent sets of experiments large additions of copper actually produced an increase in tool life and the cutting speed.

With an increase in tin to about 0.6 per cent, there was likewise no appreciable change in the roughing lathe tool performance, but with higher proportions of tin the cutting speed decreased appreciably.

[7]See footnote (4).

In general, the performance of the high speed steels in rough turning was not appreciably affected by any of the additions which were made except relatively high proportions of tin.

A very different situation was encountered in the finish turning experiments where additions of any of the four elements.

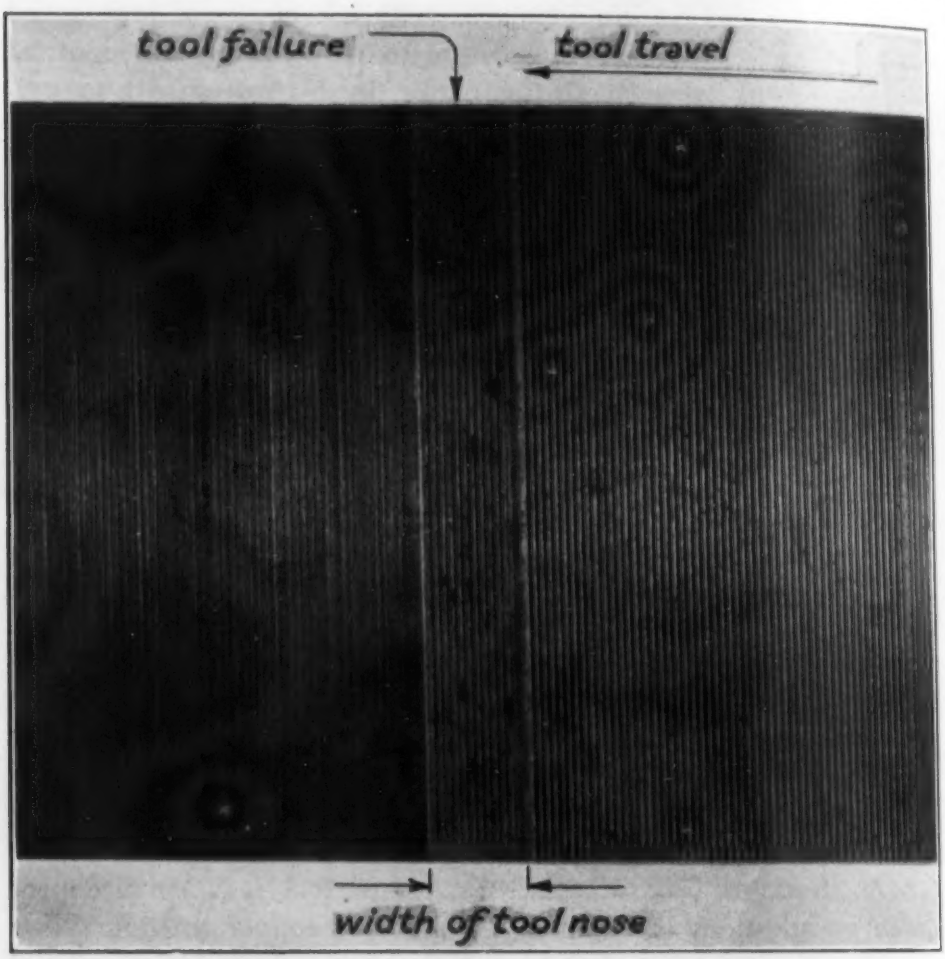


Fig. 12.—The Surface of the Machined Forging and Point of Failure of the Tool in One of the Finish-Turning Tests. Cutting Conditions are those Recorded in Fig. 10. Magnification 3.5x.

antimony, arsenic, copper and tin, produced a marked decrease in the average tool life. Copper was the least harmful; next in order came tin and arsenic while antimony produced the greatest deterioration.

The customary lathe breakdown or rough-turning tests did not give any indication of the effects observed under light cuts at high speeds, and it appears that any harmful effects of the

elements under consideration are quite largely dependent upon the type of service to which the high speed tool steels are subjected.

As previously indicated, the results summarized in Fig. 10 represent preliminary work and do not indicate what proportions of the different elements may be present before finishing-tool

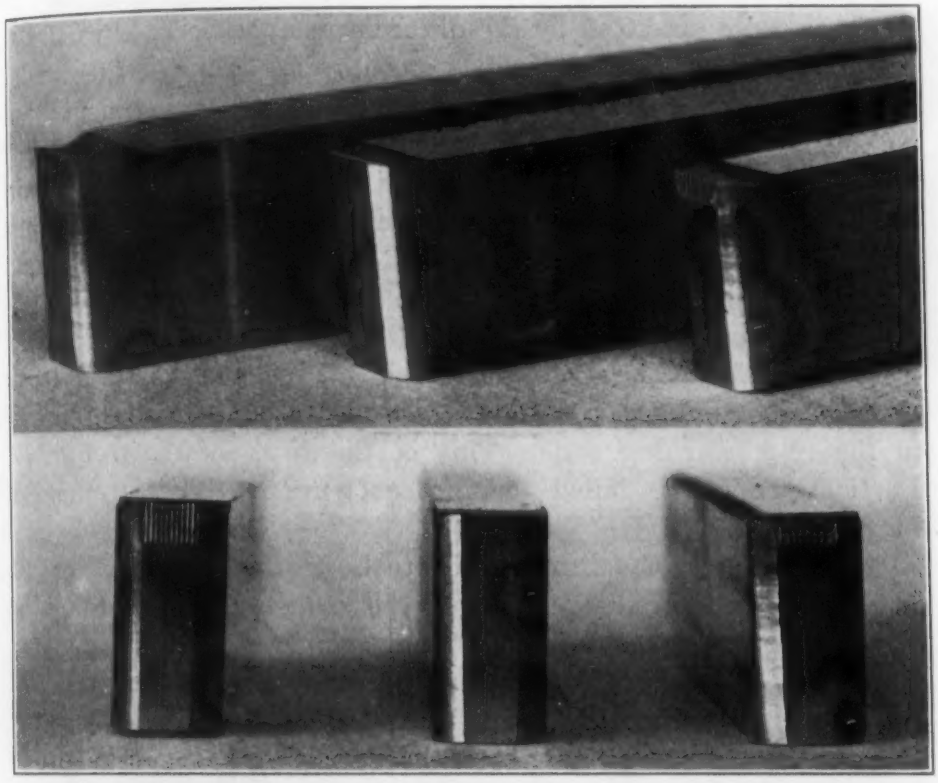


Fig. 13.—New and Failed Tools from the Finish-Turning Tests. Note how the Cutting Edge of the Worn Tools has been Rubbed off. New Tools are at Center and Failed Tools at the Sides of the Photograph. Magnification about 2.5x.

performance is noticeably decreased. However, the generally sharp drop in the average tool life with increase in antimony, arsenic or tin indicates that these metals should be kept at the lowest practicable limits. Copper appears to be less harmful than the three other elements but should likewise be kept at low values.

Additional tool tests were made with the steel containing arsenic to show that the deleterious effects of this element in the first set of finish-turning tests were reproducible. These additional tests are included in Table IV and summarized graphically in Fig. 11. They were carried out under somewhat coarser feed

but smaller depth of cut than the first set of finish-turning tests. Comparison of Fig. 11 with Fig. 10 will show that the reduction in tool life ascribed to arsenic is not restricted to a particular set of experiments.

Records were kept of the surface condition of the steels cut in the finish-turning tests. It was found that the differences produced by individual tools of one composition were generally as great as those produced by the different compositions. Practically all of the tools left a moderately smooth and shiny surface under the speeds, feeds and depths of cut used in the experiments, but as the wear of the tool progressed the surface of the steel being cut showed more and more distinct corrugations. These features are illustrated in Fig. 12. The character of the finish just before complete failure of the tool is shown enlarged at the right side of the photograph while the finish at earlier stages is illustrated at the left side.

Although the wear on the finish-turning tools seemed to be progressive, complete breakdown was abrupt and definite just as in the rough-turning tests. This is, likewise, shown in Fig. 12. Particles from the failed tool are shown embedded in the test forging.

The manner of failure of the tools is illustrated in Fig. 13. The nose was rubbed off in much the same way as in roughing cuts but without the high frictional temperatures. In general, the rubbing-off process started at the entering edge of the tool and gradually progressed across the face to the trailing edge. The actual mechanism by which the corrugations were produced which are illustrated in Fig. 13 cannot be explained but these seemed to correspond to the corrugations on the surface of the metal cut (Fig. 12). The size and spacing of the corrugations appeared to depend upon the feeds and depths of cut used in the tests. This is illustrated in Fig. 13 where the tools at the left side of the photograph were used at 0.0115 inch feed and 0.010 inch depth while those at the right were tested under a feed of 0.0154 inch and a depth of 0.005 inch.

The methods of test used cannot be said to be the best ones for finish turning because only preliminary work has been done. However, they have given consistent results, as is shown by the comparisons made in this report, and, therefore, may properly

be considered along with the more generally used rough-turning tests.

Summary and Conclusions

Preliminary tests were made of high speed steels containing added (not residual) antimony, arsenic, copper and tin. The steels were of the low-tungsten high-vanadium type and contained up to 1.7 per cent antimony, 0.8 per cent arsenic, 1.8 per cent copper or 1.8 per cent tin.

Each of these four elements adversely affected the hot-working properties of the high speed steels, but several tenths of 1 per cent of antimony or arsenic, around 0.8 per cent of copper and relatively high proportions of tin were required before noticeable effects were produced. All of the high speed steels could themselves be readily machined when in the annealed condition except the steel containing about 1.8 per cent copper.

Small additions of antimony, arsenic, copper and tin, around 0.1 to 0.4 per cent, did not materially affect the grain size of samples oil-quenched in the ordinary manner from 2350 degrees Fahr. (1290 degrees Cent.). Increase in copper tended to increase the grain size while increase in antimony, arsenic or tin tended to reduce the grain size.

The Rockwell hardness of the high speed steels was not appreciably affected by the additions of antimony, arsenic or copper when the steels were subjected to comparable heat treatments under a wide range of conditions. Additions of tin produced no appreciable effects except when the steels were oil-quenched from 2000 degrees Fahr. (1095 degrees Cent.). The hardness increased with increase in tin up to about 0.57 per cent; further increase in tin resulted in a decrease from the maximum hardness.

The effects of each of the elements, antimony, arsenic, copper and tin, on tool performance was relatively small in rough turning and did not correspond at all to the effects observed in finish-turning tests, under light cuts and high speeds. Large proportions of tin (1.8 per cent) appreciably reduced the Taylor speeds in rough turning while no appreciable changes were observed with copper up to 1.8 per cent, antimony up to 0.4 per cent or arsenic up to 0.8 per cent.

Each of the four elements appreciably reduced tool life in the finish-turning tests. Copper was the least harmful; next in

order came tin and arsenic, while antimony produced the greatest reduction in tool life.

The permissible limits for each of the four elements under consideration and the magnitude of the effects they produce appear to depend largely upon the character of the service for which the high speed steels are intended. While only preliminary tests were made and further work is in progress, the character of the results indicates that each of these elements should be kept at low limits, where general service is in view. For rough turning, small amounts of antimony, arsenic, copper or tin seem much less important.

MANUFACTURE AND USE OF HIGH-STRENGTH STRUCTURAL STEEL FOR BRIDGES

Abstract

This series of four papers constitutes a symposium on the subject of bridge steels recently presented before the New York Chapter of the society and each of the authors has treated a separate phase of the subject.

It is pointed out that due to the increase in live loads on long span bridges, the aim of the bridge builder is that of reducing the weight of spans by the use of high-strength materials, permitting higher intensities of stress. Strong steels for bridges were first introduced in this country in the form of drawn wire for cables. Nickel steel has since been used for bridge members. Mayari steel has been used and also silicon steel. It is stated that acid open-hearth steel is a superior steel for suspension cables, based on practical experience and the service it has given, in addition to the usual tests. The manufacture of wire used for bridge cables is described and the suitability of heat treated parts for service covering a period of many years is discussed. It is pointed out that steel manufacturers are willing to cooperate in the manufacture of special steels for these special purposes.

High-Strength Steel For Modern Bridges

By L. S. Moisseiff[1]

When we consider the evolution of bridge engineering and look for its activating causes we find two main factors. One is the advance made in the understanding of the functions of the structure and its behavior, the other is the improvement in the building materials which have become available for fulfilling these functions. The understanding of structures is taught to us in treatises and studies, in analytic and graphic methods and in records of research and tests. For this knowledge we turn to the mathematician and physicist.

For the material into which to embody his design the engineer turns to the makers and fabricators who from ores produce the metals on which most of our material progress of today is

[1]The author, L. S. Moisseiff, is consulting engineer for the Port of New York Authority, and designer of the Philadelphia-Camden bridge.

based. The bridge engineer acting as a professional expert and as the trusted agent of the owner turns to the manufacturer, as the producer, and asks him to supply the materials which should be suitable for the construction of his bridges. He demands materials which should be dependable in action, uniform in behavior, readily and definitely inspected and withal economical in cost. Broadly viewed this is but another expression of the law of our existence: The interplay of supply and demand.

The beginning of modern bridge engineering as distinguished from the older traditional empiricism, dates from the time when a bridge ceased to be for its builder merely a mass and began to be realized as a force clad in stone, wood or iron. Since then a bridge was not any more a massive structure like the old stone arches, impressive to the eye, by its great weight and bulk, but it began to be viewed mentally as a system of forces in equilibrium. From that time on the science of bridge engineering manifests its trend away from heavy masses toward an expression of the acting system of forces. It finally found this expression in the articulate structures of recent times. At first engineers conceived these structures merely as static forces in equilibrium and the material on which the forces acted as rigid. With later experience it was realized that the structures are not rigid, that the material is yielding and elastic and that bridges deformed with traffic, wind and temperature. It soon became apparent that for the purpose and the safety of the structure the magnitude of these deformations must remain within certain limits and be able to be controlled in the design of the bridge. These deformations of a bridge or its stiffness depend on the geometrical form given to it and on the behavior of the constituent materials.

As long as mass and weight were the controlling factors in engineering structures, materials of high strength, as we understand them today, were seldom wanted to resist the acting forces. When well arranged the stresses were then moderate and the distortions small. But with the introduction of the articulate structure the members began to lose in size and the demand on the material to increase. The members of a bridge truss began to be designed to fulfill their functions in the most direct manner and at the least expense of material. Higher strength materials thus became desirable, both for strength as well as economy.

The tendency toward stronger materials in engineering is accelerated to a higher degree by the technical function of bridges. Essentially a bridge is a structure which spans a horizontal distance by transferring the gravitational forces in the span to its abutments in a concentrated form. This is accomplished by the structure acting as a system of forces in equilibrium. The magnitude of the forces increases with the loads on the span and with their distance from the bridge abutments. Evidently, the longer the span the heavier will be the bridge and the greater will be the forces required to uphold the equilibrium. To resist these forces acting through the material of the bridge, either more material and therefore still more load is required, or a material of higher strength must be substituted which will resist the greater forces without adding to the weight of the structure. This states in different words what is known to all of us, that with an increase of span a bridge becomes heavier more than in a simple proportion. Thus in the longest highway bridge under construction, the Hudson River bridge, the ratio of dead load to live load becomes five to one.

The aim of all bridge engineers, therefore, has always been to reduce the weight of the longer span bridges by the utilization of materials of higher strength. The history of bridge engineering shows that almost in all instances of longer span bridges their designers have endeavored to obtain a material which either by its strength or dependability would enable them to allow higher intensities of stress, and thus reduce the weight to be carried. Generally, this has been accomplished with more or less success.

As a rule the new material must be produced under special conditions and with more care and involves increased rejections which results in higher cost of production. It may also be more severe on the tools used in its fabrication and it, therefore, has to be bought by the consumer at a higher price. In time its successful production and fabrication becomes established and the price often decreases. It then comes into use also for shorter span bridges and other structures where it meets conditions and proves to be economical.

Let us go back only as far as the present century. In the design of the Queensboro bridge in New York City, in 1902,

nickel steel was for the first time used in the eye-bars with a specified elastic limit of 48,000 pounds per square inch for full sized tests of 16x2-inch bars, an ultimate strength of 85,000 pounds per square inch, an elongation of 9 per cent in 18 feet and a reduction of area of 40 per cent. Later during the erection it was found convenient to use nickel steel for the riveted shoes on top of the towers. Altogether about 6000 tons of nickel steel was used in a total of 53,000 tons.

The stiffened chain design proposed at the same time for the Manhattan bridge was based on eye-bars of the same quality and on nickel steel chords built of angles and plates. The wire cable design of the Manhattan bridge, as actually built, was based, in 1906, on stiffening trusses of nickel steel for chords and web-members.

The advantages of introducing nickel steel as a high-strength material in bridge building was quickly appreciated by engineers and it was soon utilized in the design of some of the most notable bridges. In the Quebec bridge, the longest built cantilever, the lower chords in the cantilever arms were made of nickel steel and 16,300 tons of nickel steel were used in a total of 66,500 tons, or about one-quarter of the tonnage. For the 668-foot long simple trusses of the Free bridge in St. Louis, nickel steel throughout was used, eye-bars as well as compression members. More recently the chords of the stiffening trusses of the Delaware River bridge in Philadelphia were built of nickel steel.

The use of nickel steel for bridges was much stimulated by a very valuable paper by J. A. L. Waddell published in 1909 in the *Transactions* of the American Society of Civil Engineers entitled "Nickel Steel for Bridges". It contains comparative tests and studies of nickel and carbon steel extending over three years. It is an exhaustive study of the subject. In 1914 Mr. Waddell still further advanced the case of high-strength steel by his excellent paper before the American Society of Civil Engineers on "The Possibilities in Bridge Construction by the Use of High-Alloy Steels." Therein the author has made extensive estimates and brings comparative diagrams of weight and cost of steels varying from an elastic limit of 35,000 pounds per square inch for carbon steel to one of 50,000 to 100,000 pounds per square inch for alloy steel, as well as for material costing 0.5 to

5.5 cents per pound more than carbon steel. Soon thereafter the first rumbles of the European war were heard and bridge plans were generally laid aside for the more urgent needs of the war.

Meantime both engineers and metallurgists were in search for a higher strength steel which could be produced and fabricated at a moderate cost. And in 1915 we see Mayari steel used by Ralph Modjeski in the Harahan bridge at Memphis, meeting specified requirements of 55,000 pounds per square inch elastic limit and 85,000 to 100,000 pounds per square inch ultimate strength on standard test specimens, and 47,000 and 80,000 pounds per square inch minimum respectively, on full sized eyebars. Mayari steel is a natural alloy of nickel and chromium made of an ore mined in Cuba. As a natural product it has the advantage of low cost, but it also has the disadvantage of nonuniformity, varying between wide limits. For some reason or other this promising material has been withdrawn from the market.

In 1915 we encounter for the first time in the bridge engineering field silicon steel. For the Metropolis bridge over the Ohio River, built by the same eminent engineer, a silicon steel was specified having a yield point of 45,000 pounds per square inch, an ultimate strength of 80,000 to 95,000 pounds per square inch, a reduction of 35 per cent and an elongation of at least 17 per cent. Silicon steel of the same requirements was also used in the Cincinnati bridge in 1917 and since then it has become a favored material for bridges. At the present time producers generally charge for it a differential of not more than a cent per pound over the price of carbon steel and frequently less. It is an economic and dependable material. It has been used to a large extent in the recently completed Delaware River and Carquinez bridges and the Mid-Hudson bridge now under contract. The largest tonnage of silicon steel will be consumed in the recently contracted towers and floor of the Hudson River bridge which will amount to 32,000 tons. The recent standard specification for structural silicon steel adopted in 1927 by the American Society for Testing Materials call for:

	T. S.
Tensile strength, pounds per square inch	80,000 to 95,000
Yield point, minimum pounds per square inch	45,000
	1,500,000
Elongation in 8 inches, minimum per cent	———
Reduction of area, minimum per cent	30

About twelve years ago another new material for eye-bars made its appearance in the bridge engineering field. These bars are of carbon steel and heat treated and are offered to the consumers in two grades meeting the following minimum requirements in full size tests:

	Grade 1	Grade 2
Tensile strength, pounds per square inch	105,000	80,000
Yield point, pounds per square inch	75,000	50,000
Elongation in 18 feet per cent	5	8

The second grade heat treated eye-bars have been used in a number of bridges and recently in the Carquinez bridge, where about 1400 tons of bars were consumed. The first grade was used in the Florianapolis bridge, Brazil. About 800 tons of these bars were consumed.

Heat treated steel is quite a newcomer among materials employed in bridge building and the use of this material in as highly individualized a member as an eye-bar has caused hesitation in the minds of many engineers as to the higher grade bars and the consequently higher stresses to be allowed for them. It must be admitted that the record of tests of full sized eye-bars so far made is good. It should, however, be considered that each bar is heat treated separately and that consequently by selecting a number of bars for breaking tests these selected bars do not represent samples of groups of identical bars, but only themselves individually. The results of the tests are informative in a statistical manner and the assurance of the behavior of the untested lots used in the bridge is based on probability only. It seems to the writer that a more reliable method of selecting and testing should be evolved.

Since Messrs. White and Hazzard in this country in 1816 and Séguin Frères in France in 1826 introduced drawn wire for bridge cables, wire in one form or another became important material for the builder of either light weight or long span bridges. With a very few exceptions suspension bridge cables have been built of wire. The available bridge wire has with time undergone many improvements and, it may well be stated here, has attained a high degree of perfection and strength. The improvement has been in the selection of the material and the process of manufacturing. It has been gradual. Since the wire used in the Brooklyn bridge till today the evolution has been in the di-

rection of a higher elastic limit and a greater strength. No new methods or new alloys have been brought forward.

The growth in ultimate strength of wire used in the largest suspension bridges is shown in the following tabulation:

Bridge	Date	Specified Ultimate Strength, Lbs. per Sq. In.
Brooklyn	1880	160,000
Williamsburg (N. Y.)..	1900	200,000
Manhattan	1906	210,000
Delaware River	1923	215,000
Hudson River	1927	220,000

Only recently an improvement in wire making by means of heat treatment has been brought forward.

Metallurgists are better informed than bridge engineers as to characteristics of heat treatments and the possible advantages that may be obtained as well as to the possible dangers that may be incurred. Doubt has been expressed as to the effect of time on heat treated steel. The question has been raised whether the qualities acquired through the heat treatment will endure during the many years the member is expected to function. Naturally engineers are anxious for positive information. I believe it is up to the manufacturers to inaugurate exhaustive tests to settle the question.

If I may then resume my thoughts expressed here, I have attempted to present to you a few indications of the trend in bridge building and a brief history of the use of alloy steels. I have done this in order to better substantiate the demands which the bridge designer makes on the producer of steel.

Bridges should be strong enough to carry their loads and stiff enough to act well as structures and to remain comfortable for travel. For stiffness, not a high-strength material is required, but sufficient material of standard strength properly placed. For this purpose low-strength material of good ductility, low in cost of manufacture and low in cost of fabrication is wanted. For this reason most details, except such as transmit principal stresses directly like splices and gusset plates, are made of common structural carbon steel. In most cases bracing members, hangers, local posts and the like can be made of lower strength material. So can almost all the floor material.

For carrying strength, of course, the higher strength metals

are desirable. For this purpose materials of various strengths according to the character and functions of the members are wanted. Such material must at the same time have sufficient ductility to sustain without injury the more or less violent processes of fabrication and to be able to well distribute stresses concentrated on small areas such as caused by rivets or by abrupt changes in section.

To transmit the greater stresses which are sustained by members made of higher strength steel, riveted connections of greater strength are naturally required. Designing these connections for the rivet steel commonly used requires an increased number of rivets which are difficult to place and result in splices of excessive length. It is well known that as the numbers of rows of rivets increase the efficiency of the joint decreases. Recourse has been made in recent times to larger size rivets but even this expedient is soon exhausted. Nickel steel rivets have been largely used and when carefully handled and driven and with a thorough inspection have given good results. Many inspectors and engineers and, I believe, also erectors are, however, not satisfied with nickel steel as a riveting material. There is a manifest demand for a higher strength rivet steel which could be conveniently heated without forming scale, should easily upset and fill the hole and furnish a dependable rivet when in place.

With the growth of bridges and the enormous increase in the reactions they transfer to piers and abutments a greater demand is made on castings suitable for bearings and saddles. As steel castings can be made of substantial thickness there is generally no difficulty in providing sufficient section in the casting to keep the unit stresses down and no high-strength steel is required to meet conditions. Nor is the cost of the material used in the casting of prime importance. Commonly, steel castings are used which develop not less than 65,000 pounds per square inch in tensile strength, 35,000 pounds per square inch yield point, 20 per cent elongation in 2 inches and 30 per cent reduction in area. The question here is altogether one of dependability. Bridge engineers to their chagrin are only too well acquainted with cracks and even failures appearing in important castings days and months after they have been annealed and passed by experienced inspectors. There is an urgent need for reliable cast-

ings and the art of the metallurgist, of the foundry men and of the steel specialist may well be combined to produce large, strong and dependable castings so that the bridge builder may be as sure of their behavior as he can be of that of structural steel members.

The growth of transportation by mechanical vehicles and the widely spread rise in the financial standing and buying capacity of our population have increased enormously the number of vehicles on our highways. A great improvement in the character of these highways and in their mileage has followed. Now the demand is for shorter routes over large rivers, for the avoidance of delays due to ferries, in short, for long span bridges. These bridges will be mostly used for highway purposes. They do not, as railroad bridges do, form part of a great system where the cost of the individual bridge is merged in the cost and productivity of the whole. The long span bridges which will be built in the near future will be mostly toll bridges and will be financed on their earnings. They must pay for themselves and show profit. They, therefore, have to be economically planned and maintained at low cost. As far as the bridge structure itself is concerned it is largely then a matter of the materials available and how economically they can be bought. This, in the writer's opinion, points to high-strength structural steels as a source of economy and it offers a splendid opportunity to metallurgists to advance the art of long span bridges and so accelerate the rate of the material progress of humanity.

Manufacture Of Acid Open-Hearth Steel For Suspension Cables

By H. C. Boynton[2]

IT may be impossible to convince all of you in fifteen minutes as to the superiority of acid open-hearth steel over basic open-hearth steel, suitable for suspension bridge cables, but it is the belief of the company which I represent that over sixty years of practical experience and service should bear more weight in a technical problem involving human life, than experiments based on theory alone. We believe that the Cincinnati, the Brooklyn,

[2]The author, H. C. Boynton, a member of the society, is metallurgist for the John A. Roebling's Sons Co., Trenton, N. J.

the Williamsburg, the Manhattan, the Bear Mountain and the Philadelphia-Camden bridges, particularly the first four mentioned, are all standing monuments testifying as to the endurance qualities of acid open-hearth steel cables. Wires taken from some of these bridge cables after many years of service show properties identical with the newly fabricated wire, and barring some unusual catastrophe like an earthquake, such bridges will be giving service when we are all dead and our children and grandchildren are also gone.

Many years ago, about 1865, our founder, John A. Roebling, formulated the standard, and later his son, Col. Washington A. Roebling, established the rule, that wire for suspension bridge cables should be made of the best steel that money could buy, (excepting, of course, crucible steel, of which there was not enough in existence at that time to make a large bridge cable), and in these days as well, the standard originated is still adhered to, namely, that acid open-hearth steel is the best for fabricating into a wire which is laid parallel in a bridge cable, then bundled into strands and later all the strands compressed into a circular cable that must hold many tons of human freight.

Consequently, acid open-hearth steel made of Swedish pig iron was first used for cables, the steel being imported from England; later competition became keen, the price of such imported wire became too high, and the American acid open-hearth steel began to equal or better the English, so that American steel came into use. Later the John A. Roebling's Sons Company built its own steel mill and now and for the past twenty years has been making its own acid open-hearth steel out of the purest low phosphorus and sulphur pig iron and ore that can be purchased in the United States, plus its own analyzed scrap, melting the charge down with low-sulphur fuel oil, analyzing at frequent intervals, and employing all the best known methods of steel melting practice.

The rule, "acid open-hearth steel for highest grade rope and cable wire", has been proved to be "right" by the actual practice of all the best wire manufacturers in the United States, and is substantiated by the fact, that although they all make basic open-hearth steel (as we do), when they want a rope or cable to stand the severest service possible, like dredging or logging, they all use acid steel.

These statements are probably "ancient history" to some of you, but in addition to the above proven practice, I am going to go farther and explain to you some of the technical reasons why we think acid open-hearth steel is superior to basic. Briefly, this superiority we think is due to the following physical, chemical and structural properties.

(1) Acid open-hearth steel is freer from solid non-metallic impurities. We have many times analyzed acid and basic open-hearth steel and have had our analyses checked by the most reputable chemists in the United States and always find the item "total slag and oxides" to be greater in basic than in acid steel, often two or three times the amount of the former over the latter.

(2) Acid open-hearth steel has a greater freedom from included gases, which fact probably follows from the statement made above, namely, the more "slag and oxides" the greater the tendency of the steel to absorb gases.

(3) Acid open-hearth steel with the same chemical composition practically always has a higher tensile strength and elastic limit than basic open-hearth steel. Why this is so, never has been satisfactorily explained, but figures tell us that it is true.

(4) Acid open-hearth steel has greater uniformity day in and day out in physical, chemical and microscopical properties.

The combination of the above factors have all been shown by actual experience to give acid open-hearth steel a greater endurance limit or greater resistance to fatigue stresses than basic open-hearth steel. What fatigue tests that have been made show conclusively that the fatigue cracks, almost invariably originate at the slag and oxide inclusions.

In closing, may I say that granting that the above is true, and experience shows it to be so, and knowing the good uniform properties of acid open-hearth steel, why add the uncertainty of service that *might* arise from the use of basic open-hearth steel? Why did the users of Bessemer steel rails go to open-hearth steel rails? Simply because they found that open-hearth steel was more uniform physically and chemically in all its properties than Bessemer steel. For exactly the same reason acid is more reliable than basic open-hearth steel. It may be that sometime in the future a new type of steel may be discovered which will be cheaper

and stronger and better than the best acid open-hearth steel, but at present no such discovery is on the horizon, and until such a super metal, cheap enough to be manufactured in large tonnages is evolved, why go further and substitute any uncertain material when human lives may be sacrificed by such an experiment? We believe that we should play safe and always use the best material obtainable (within a reasonable price) for our suspension bridge wire cables, and that is acid open-hearth steel.

Drawn Wire And Its Heat Treatment

By A. V. de Forest[3]

WIRE for suspension bridges has heretofore been manufactured under the same general conditions as high grade rope wire. Steel with a carbon content of about 0.80 per cent is hot-rolled into rods which are then given a particular heat treatment, termed patenting, (in reality a sorbitizing process) and then drawn cold through several dies of different diameters to the finished size. In the form of patented rod, the wire will have a tensile strength of from 130,000 to 160,000 pounds per square inch. However, the ductility of this patented structure is greater than that of similar material annealed which would have a much lower tensile strength. After drawing, the stress-strain characteristics of the wire are represented by the curve for bright wire in Fig. 1. At 0.70 per cent elongation the conventional yield point would be 142,000 pounds per square inch but the breaking strength would be very high in comparison, perhaps reaching 275,000 pounds per square inch, with a total elongation of 1.5 per cent. This hard drawn wire is then galvanized in order to protect the surface from corrosion. The mechanical properties are greatly affected by the heat treatment accompanying hot galvanizing. The structure is partially re-crystallized, the tensile strength is lowered, the elongation is markedly increased and the yield point and modulus of elasticity are improved. Galvanized wire such as used for the Delaware River bridge is also shown in the figure and under good conditions would have a tensile strength of around 228,000 pounds per square inch with a yield point of 150,000 pounds per square inch and an elongation above 4.5 per cent.

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[3]The author, A. V. de Forest, a member of the society, is research engineer with the Page Steel and Wire Co., Bridgeport, Conn.

For the Hudson River bridge, attempts were made to improve this product by further improving the strength of the hard drawn bright wire before galvanizing. The characteristics of this type of material are also given in the diagram as the upper curve labeled "galvanized". About the maximum limit is a breaking strength of 243,000 pounds per square inch with a yield point of 153,000 pounds per square inch and somewhat less elongation than at the

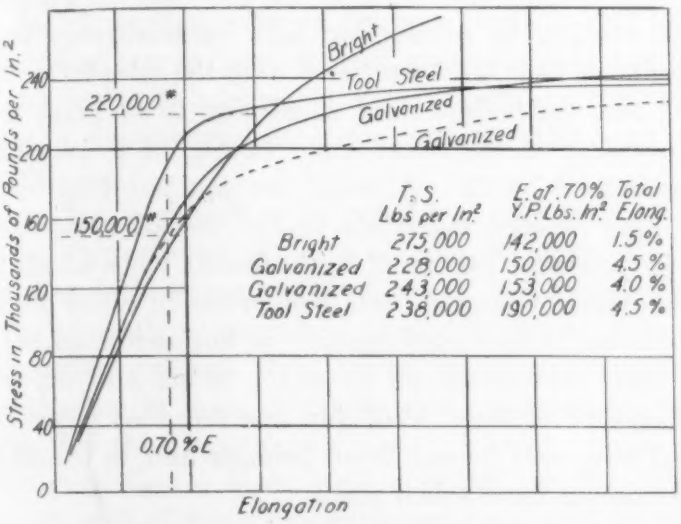


Fig. 1.—Stress-Strain Characteristics of Wire After Drawing.

lower figure. This increased strength is obtained at the expense of ductility as measured in other ways and the wire does not appear to be as reliable or generally satisfactory as the softer stock.

Another system of wire making has been developed for bridge work which shows a marked improvement over the figures quoted above. In this case, instead of wire hardened by cold working, a fully heat treated steel was used in the quenched and tempered state. The characteristics of this are shown in the diagram under tool steel which to all intents and purposes this material actually is. The breaking strength is not particularly higher than that obtainable by cold working and galvanizing, but the yield point and modulus of elasticity are very markedly improved, the former being raised to 190,000 pounds per square inch without any sacrifice of elongation. This material of course must be studied under working conditions in order to compare its properties with those of the previous type. All indications point to a possible substantial increase in working load which can be handled with this process.

Mr. Moisseiff has referred to the improvement which has taken place in structural steel for bridge work, particularly in regard to the use of alloys and heat treated material. Improvement due to heat treating of steel has made such rapid strides in recent years throughout the automobile and machinery fields that this source of increased strength should logically be further developed for bridge work. Heat treated eye-bars of large dimensions are now in use and appear to fulfill the requirements. In the case of wire, the small section and continuous production add immeasurably to the ease and continuity of heat treatment and with the adaptation of special methods of test we believe that reliability is as great or greater than that obtained in the usual way. In regard to possible secular changes mentioned by Mr. Moisseiff, we can point to very old examples of heat treated materials in the use of arms and armor. There are in existence plenty of heat treated tools which have not, as far as we know, changed their properties in many hundreds of years. Of course, direct confirmation is impossible as the original properties were not measured in exact terms and are even now difficult to make complete. Probably one hundred years from now heat treated wire will be cut from bridges and re-tested to determine what changes have taken place.

Changes due to aging are marked in the cold drawn materials. Fortunately the change is always in the direction of higher strength although at the expense of ductility. This is to be expected from a material hardened by cold work and therefore in unstable equilibrium and filled with internal stress.

We quite agree with Mr. Moisseiff in his desire for better knowledge of high-strength steel, better methods of test which will increase our confidence in this material and allow an increase in the working loads which in turn will make it possible to build longer and lighter bridges than have yet been contemplated.

Silicon Structural Steel For Bridge Construction

By H. T. Morris[4]

I HAVE been asked to talk to you for about 15 minutes concerning problems connected with the production of the silicon

[4]The author, H. T. Morris, a member of the society, is metallurgical engineer for the Bethlehem Steel Company, Bethlehem, Pa.

steel used in the Philadelphia-Camden bridge. It will, of course, be necessary to avoid much detail to keep within this time limit. As the Bethlehem Steel Company manufactured, fabricated and erected the towers for this bridge, I will confine this talk to the silicon steel used in those towers, the contract for which was awarded December 1, 1922.

Each tower is 343 feet high from the top of the masonry pier to the bottom of the cast steel cable-saddle which surmounts it; is 38 feet 8 inches wide at its base and 12 feet wide at its top. The tower top is being pulled away from the vertical position by the varying horizontal components of the pull in the cables due to temperature changes and to load changes and to other conditions.

I quote Mr. Moisseiff with regard to the tower design (*Engineers and Engineering*, Volume 42, No. 6, page 140):—"It has been seen that for a given width of tower, certain bending stresses will naturally result independent of the thickness of the material. It was therefore evident from the start that the use of steel of higher elastic limits than that obtained in the usual carbon steel is desirable for the tower legs."

The higher elastic limit steel specified by the engineers for about 70 per cent of the rolled structural material in these towers (the total weight of which structures is about 10,000 tons) was a type of silicon steel which had been previously occasionally used for large span bridges. The first of these was the C. B. & Q. R. R. double track bridge, crossing the Ohio River southward from Metropolis, Illinois, commenced in 1915. Mr. Ralph Modjeski, chief engineer of the Delaware River bridge, was consulting engineer for the Metropolis bridge, C. H. Cartlidge having been the bridge engineer.

This rolled structural silicon steel consisted of riveted members composed of plates and angles. Most of the angles were 8x8x¾ inches by varying lengths, up to 100 feet. Most of the plates were ¾ inch thick, but of various lengths and breadths. The heaviest sheared plates in the towers were ordered to finish ¾x134x339 inches weighing an average of 10,300 pounds. These plates were rolled directly from bottom-poured soaking-pit heated ingots. The ingots (22x68 inches weighing 17,400 pounds) were made in basic lined open-hearth furnaces. One plate was rolled

from each ingot. Rolling was stopped on some ingots so as to allow chipping of defects, after which the block was re-heated and re-rolled to finished gage. Some of the plates, however, still contained slight snakes or other defects which made them unacceptable to the purchaser. These had to be cut into much smaller plates or thrown into scrap. Because of rejections, the actual yield obtained from ingot to finished plates was about one-third less than would have been obtained from the same sized plates in standard grade structural steel.

The widest sheared plates were ordered to finish ¾x154x167 inches. Eight of these plates, averaging 5690 pounds each, were rolled from four basic open-hearth bottom-poured 22x68-inch 18,800-pound ingots. The major plate tonnage was rolled from top-poured basic open-hearth ingots. Plates of a variety of widths up to 99 inches and lengths up to 501 inches formed parts of these rollings. The wider plates were rolled on a 110-inch three-high sheared-plate mill. The narrower plates constituting about 30 per cent of total plate weight, were rolled on the 60-inch universal mill.

All the plates were rolled from slabs bloomed from top-poured basic open-hearth 28½x40-inch 20,000-pound ingots, soaking-pit heated. The slabs were reheated in gas-fired horizontally charged furnaces for finished rolling in the 110-inch or 60-inch mills. Slabs were allowed to cool off, then examined and carefully chipped before reheating for finished rolling. The yield of all plates from ingots was one-fifth less than normal for standard structural grades on the small mills.

All the angles were rolled from blooms reheated in a gas-fired continuous furnace feeding the structural mill. These blooms were rolled from basic ingots, top-cast. Subsequent inspection of the finished angle bars which were rolled in lengths of 100 feet or more, resulted in substantial rejections for defects principally in the flanges.

The yield of acceptable angles from a typical group of about 1200 tons of 21x27-inch 11,000-pound ingots was approximately nine-tenths of that obtained from standard structural grade angles rolled on this mill.

The chemical specification for basic silicon steel as laid down by the commission is given in the following tabulation. Drillings

from a test ingot taken during the pouring of each melt were analyzed. The second column of the following table shows the analysis of check drillings as made by the commission from finished material:—

	Commission Specification	Check Drillings
Carbon (max.)	0.40	0.44
Manganese (max.)	1.00	1.10
Silicon (limits)	0.20 to 0.40	0.18 to 0.44
Phosphorus (max.)	0.04	0.05
Sulphur (max.)	0.05	0.063

Material up to and including ¾ inch thickness (this covered practically all material furnished by us) was specified to the following tensile test properties:—

Tensile Strength Lbs. per sq. in.	Yield Point Lbs. per sq. in.	Elongation in 8 in.	Reduction of area
80,000 to 95,000	Not less than 45,000	$\frac{1,600,000}{\text{T. S.}}$ = 20% for 80,000 lbs. T. S. or 17% for 95,000 lbs. T. S.	Not less than 35%

Bend test specimens from the ¾-inch silicon steel material were obliged to bend 180 degrees without fracture around a bar ¾ inches in diameter. Full sized sections sawed from the angles were required to withstand without rupture, cold opening to an angle of 150 degrees or cold closing to an angle of 30 degrees.

The manufacture of the steel was conducted in three different open-hearth plants; and the procedure varied to the extent that the practice and equipment of these plants varied. The weight of ingots produced per melt varied from 75 tons to 95 tons. In the plant which made the 75-ton heats, additions of ferrosilicon were required more than 7 times as heavy as those for usual structural steel. Such additions, if made in the furnace, attack and seriously damage the basic linings, therefore only a part (20 per cent) of the silicon used was put in the furnace. This was added 40 minutes before tapping, as 14-per cent ferrosilicon, and the remaining 80 per cent of the silicon was added in the ladle as 50-per cent ferrosilicon. The manganese was all added in the furnace 6 minutes before tapping as 80-per cent ferromanganese. In order to protect the furnace linings from the silicon added in the furnace, 2½ times its weight of burnt line was added with the ferrosilicon.

Having touched on high silicon, I will say nothing further of steel-making problems except to note that constant care and attention are required of the open-hearth people in plants accustomed to the manufacture of the high quality steels required in the current manufacture of plates and of wide-flanged standard structural shapes. Specifications like this for silicon steel increase the percentage of "heats missed" in the open-hearth, in spite of much expert attention. This is because the allowable practical range of "hardening elements" (i. e., carbon, manganese and silicon) is reduced by the narrow zone established in the finished physical test requirements between steel that is hard enough to have the required strength and soft enough to have the required ductility.

In the heating, rolling and finishing of these high-carbon steels with silicon content higher than usual in structural materials, close temperature control is needed to meet the physical requirements, particularly the bending requirements. In our plants this is more particularly true of the plates than of the angles in the ¾-inch gage; but for both products, differences in lay-out, equipment and methods compel in different plants, different practices:—(Temperatures of charging, temperatures and times of heating, rates of rolling-reductions, time consumed in rolling, methods of hot-bed cooling, etc.).

I now leave metallurgical considerations to talk a few minutes of the economic problem connected with "strong structural steels".

High-strength steels were necessary in Mr. Modjeski's gigantic Delaware River bridge span (1750 feet). Mr. Moisseiff's Hudson River span (3500 feet) which will double that of the present giant, could not possibly be carried on the cables now available except by weight curtailment possible only with high-strength steels in the suspended structure. And the new span projected for "The Narrows", with 20 per cent greater length (4200 feet) is in the same category. These are unusual cases; and structural steel makers are glad to co-operate with designers in the production of the needed high-strength steels. All concerned recognize that these special cases demand whatever expenditures may be required to solve the problems.

As to the remaining 98 or 99 per cent of structural steel

tonnage, I wonder if we carry in mind the fact that steel is one of the few commodities that is sold by manufacturers at practically pre-war prices. Ten years before we entered the war, beams and tank plates were quoted 1.86 N. Y. tidewater. Eight years earlier, i. e., twenty-eight years ago, the quotation for beams was 2.40 at N. Y. and for tank plates 3.00 at N. Y. There have been many and wide fluctuations in the intervening years but the fact remains that last month (October, 1927), beams and plates were quoted at but 2.09 N. Y.

As in automobile manufacture so in the steel industry mass production has helped to keep down the costs of articles of standard grades in the face of much increased wages, freight rates and all commodity prices. When a special grade, such as high-carbon, high-silicon steel, is introduced into a plant operating on standard steels only, production is at once retarded. The alloys cost more, making the ingots more expensive; the ingots require greater discards, increasing the cost of the material in blooms and slabs; the heating time is increased because the furnaces must be charged at lower temperature; the finishing-mill rolling time is increased because the physical properties can be certainly attained only by controlled temperature during rolling. Problems involving difficulty and added cost arise in the necessity of keeping separate the special grade in mills, storage-yard, inspection and shipping stations.

Because of chemical restrictions, made still narrower by high tensile properties demanded, more heats are missed; and because missed heats are of grades seldom used, more ingots must go into scrap.

Plates and shapes of the special grade have not as high percentage of perfect surface as standard grades; but the inevitably higher price usually causes the purchaser or his inspector to demand more perfection in the specialty. Thus the smaller percentage of ingots which reaches the rolling mill is subjected still further to increased rejections in the finished inspection. The rejected material of special grades can usually not be applied to orders and must be cut to scrap; but even when application can be made, only small percentages can be applied.

In the fabrication of the stronger steels, the speed of drilling, reaming, planing, etc., is seriously retarded and tool cost is

materially increased. Limitations are also set upon the diameter of holes and upon the thickness of material that can be punched.

In short, to go back to the Delaware River bridge, our production capacities were reduced and costs were increased so that the ton cost of this "silicon steel" finished product—whether fabricated or unfabricated—was considerably higher than for standard structural grades; although it was a large order, about 7000 tons.

Considering silicon steel in ordinary stuctures, the price, if based on this increased cost as it should be, would thus, for nearby delivery, be proportionately higher than for standard grades, even when large tonnages are involved. Unless the purchaser of silicon steel could correspondingly diminish the weight needed for his structure, he would not gain money advantage, but he would jeopardize the promptness of his deliveries. And in any event he would injure the producer and the fabricator by diminishing their production and their per ton profits.

When only a small quantity of a special structural steel is desired, the cost disadvantage would be considerably greater. Several weeks ago a customer inquired at our Bethlehem Plant for 54 tons of silicon structural steel shapes of varied sizes. Ability to promptly deliver an order like this would entail the large expense of new yards for the storage, straightening, cold-sawing and shipping of special grades. This would mean at least a partial duplication of our present large and fully equipped standard grade yard; and would involve larger operating and inventory costs. The latter would be very high because they would involve slow-moving material; as fabricators generally are not equipped to economically handle the high-strength steels, we could not meet this customer's wishes; but if we could have done so it would only have been at high per ton cost that would have offered him no advantage over sections of usual structural grades.

STUDIES ON NORMAL AND ABNORMAL CARBURIZING STEELS

By O. E. Harder, L. J. Weber and T. E. Jerabek

Abstract

This paper is rather preliminary in nature. It reports studies on normal and abnormal carburizing steels under the following general headings:

1. *Effect of heating abnormal steels in vacuo at carburizing temperatures*
2. *Effect of heating normal steels in nitrogen, oxygen, and carbon dioxide*
3. *Effect of melting normal and abnormal steels in vacuo in alundum and in magnesite crucibles*
4. *Effect of melting normal steels in atmospheres of nitrogen and carbon monoxide*
5. *Effect of heating normal steels in contact with sonims*
6. *X-ray examination, by the powder method, of normal and abnormal steels*
7. *The normality of metals deposited by the electric arc under a number of conditions and with some alloy steel welding rods has been investigated briefly*
8. *A mechanism is proposed for the formation of the structure found in abnormal carburizing steels.*

THE following investigation was planned at the close of the school year 1925-26 and has been under way during the entire school year 1926-27. A study of the published literature, particularly the articles by McQuaid and Ehn, and by Ehn alone, and some of the experiences of one of the authors[1] on metals deposited by the electric arc, suggested that the present state of information regarding the so-called normal and abnormal steels was far from complete, and, furthermore, that the fundamental cause for abnormality of steel as well as the mechanism of the formation

[1]Weber, Studies on Electric Welding—Transactions, American Society for Steel Treating, Vol. XI, p. 425-449, 1927.

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. Of the authors, who are members of the society, O. E. Harder is professor of metallography, and L. J. Weber is instructor in metallography, School of Mines and Metallurgy, University of Minnesota. T. E. Jerabek was a senior metallurgical engineering student 1926-27, and is now with the Lincoln Electric Company, Cleveland. Manuscript received July 11, 1927.

of the abnormal microstructure required further investigation. Since that time two comprehensive papers have appeared, one by John D. Gat,[2] and the other by S. Epstein and H. S. Rawdon.[3]

The present authors have sought to convert normal into abnormal steels and vice versa by various methods of which the following are most important.

1. Change an abnormal steel to a normal steel by heating in vacuo at carburizing temperatures.

2. To change a normal to an abnormal steel by heating in various gaseous atmospheres at carburizing temperatures.

3. To change an abnormal steel to a normal steel by melting in vacuo.

4. To change a normal to an abnormal steel by melting in certain atmospheres.

5. To change a normal to an abnormal steel by heating to carburizing temperatures in contact with various materials representative of those sonims which may be present in any steel but particularly in those steels which are incompletely deoxidized or deoxidized late in the steel-making process.

In addition to the above methods of attack, use has been made of the X-ray diffraction apparatus previously described in a publication from this laboratory,[4] to determine if there is any difference in the space lattice of normal and abnormal carburizing steels.

Some additional attention has been paid to the normality of welds. It is the purpose of this paper to present the results of these experiments and in addition to offer certain theories regarding the cause of abnormality in steel and the mechanism of the formation of the characteristic abnormal structure, only a part of the theories having been reasonably well established at the present time.

Materials Used in the Investigation

Table I which follows shows the types and chemical compositions of the materials used in this investigation.

In addition to the above materials the authors have discussed

[2]John D. Gat, Abnormality of Steel, TRANSACTIONS, American Society for Steel Treating, Vol. XII, September, 1927.

[3]S. Epstein and H. S. Rawdon, Progress in the Study of Normal and Abnormal Steel, TRANSACTIONS, American Society for Steel Treating, Vol. XII, September, 1927.

[4]Harder and Dowdell, TRANSACTIONS, American Society for Steel Treating, Vol. XI, 959-974 (1927).

Table I

Steels Used in Investigation

Steel No.	Description S. A. E.	Chemical Composition C	Mn	P	S	Si
48	1020	0.20	...	....	....	...
60	Double refined wrought iron.					
64	1020	0.20	...	....	....	...
65	Ingot Iron	0.068	0.07	0.006	0.014	0.03
77	1020	0.20	0.43	0.022	0.033	...
91	1020	0.23	0.53	0.005	0.031	0.07
92	1020	0.22	0.51	0.007	0.004	0.06
Electrolytic iron		...	...	....	....	...

some results obtained by electric welding in which various types of welding rod were used; but that investigation is to be used primarily for a later paper on electric welding by one of the authors.

Preliminary Examination of Materials—The steels listed in Table I were in rods of various sizes, and in order to standardize on the size of specimens sections of each steel, about a foot long, were machined to ½-inch in diameter. From these uniform bars specimens were cut as they were needed.

A microscopic examination was made of each specimen to determine the general condition of the steels. All the steels were found to be reasonably clean, and the grain size was that which one would expect in a normalized steel. Steel 60 showed the characteristic wrought iron slag inclusions. The Armco ingot iron and the electrolytic iron appeared almost alike under the microscope, both being practically free from pearlite.

To determine the condition of these steels as regards normality, a preliminary carburizing test was made. Steels 48, 60, 64, 65, 77, 91, 92, and electrolytic iron were packed in fresh carburizing compound, in a 3″ x 4″ x 6″ carburizing box. The specimens were cleaned in gasoline, before packing, to insure against erratic results due to surface contamination. Care was taken in packing so that each specimen had at least an inch of compound on all sides. The cover of the pot was luted with a mixture of fireclay and salt to exclude air.

The heating was done in an electric muffle furnace. The furnace temperature during the carburizing tests was determined by means of a pyrometer which had been carefully calibrated. Temperature regulation was obtained by varying the number of effective turns on the transformer secondary which supplied the

furnace with power. After a little experience, the correct combination to produce a certain desired temperature was found and the furnace could be operated for a considerable length of time without attention, at a temperature which varied but a few degrees.

After carburizing at 1725 degrees Fahr. for 8 hours, the specimens were allowed to cool in the box in the furnace.

By a microscopic examination of the polished specimens, it was possible to class the steels according to their normality. Steels 77, 64, 48, 91 and 92 were found to be normal, the typical structure of which is illustrated by steel 77 in Figs. 1 and 2.

Fig. 1 is a photomicrograph of the case of steel 77, at 100 X. It shows the sharp boundaries of cementite in the hypereutectoid zone surrounding the grains of pearlite. Farther toward the center of the specimen where the carbon content is less the field consists entirely of very finely laminated pearlite.

Fig. 2 shows at 1000 X a portion of the hypereutectoid zone of steel 77 and reveals more clearly the condition of the pearlite and of the cementite at the grain boundaries. Steels 48, 64, 91 and 92 had similar appearance under the microscope.

Steel 65 is shown at 100 X in Fig. 3, from which it can be seen that the steel has a decidedly abnormal structure. The case, instead of being a network of cementite about grains of pearlite, consists of masses of free ferrite and cementite with only a few patches of pearlite. The grain boundaries are not well defined.

Fig. 4 is the hypereutectoid zone of the same specimen at a magnification of 1000 X. The large mass of light unetched material in the lower part of the photomicrograph is cementite which probably occupies the position of a grain boundary at the carburizing temperature. The light, pitted matrix is free ferrite. Here we can see almost complete pearlitic divorce, only a small amount of the eutectoid being present.

The remaining steels of the group (60 and electrolytic iron), although they appeared to be normal, had a slight tendency for coagulation of cementite and ferrite and could not, therefore, be definitely placed in either the normal or abnormal class. For this reason these steels were not considered further in this investigation.

Effect of Heating Abnormal Steel in Vacuo at Carburizing Temperatures

Working on the theory that dissolved gases may have an effect

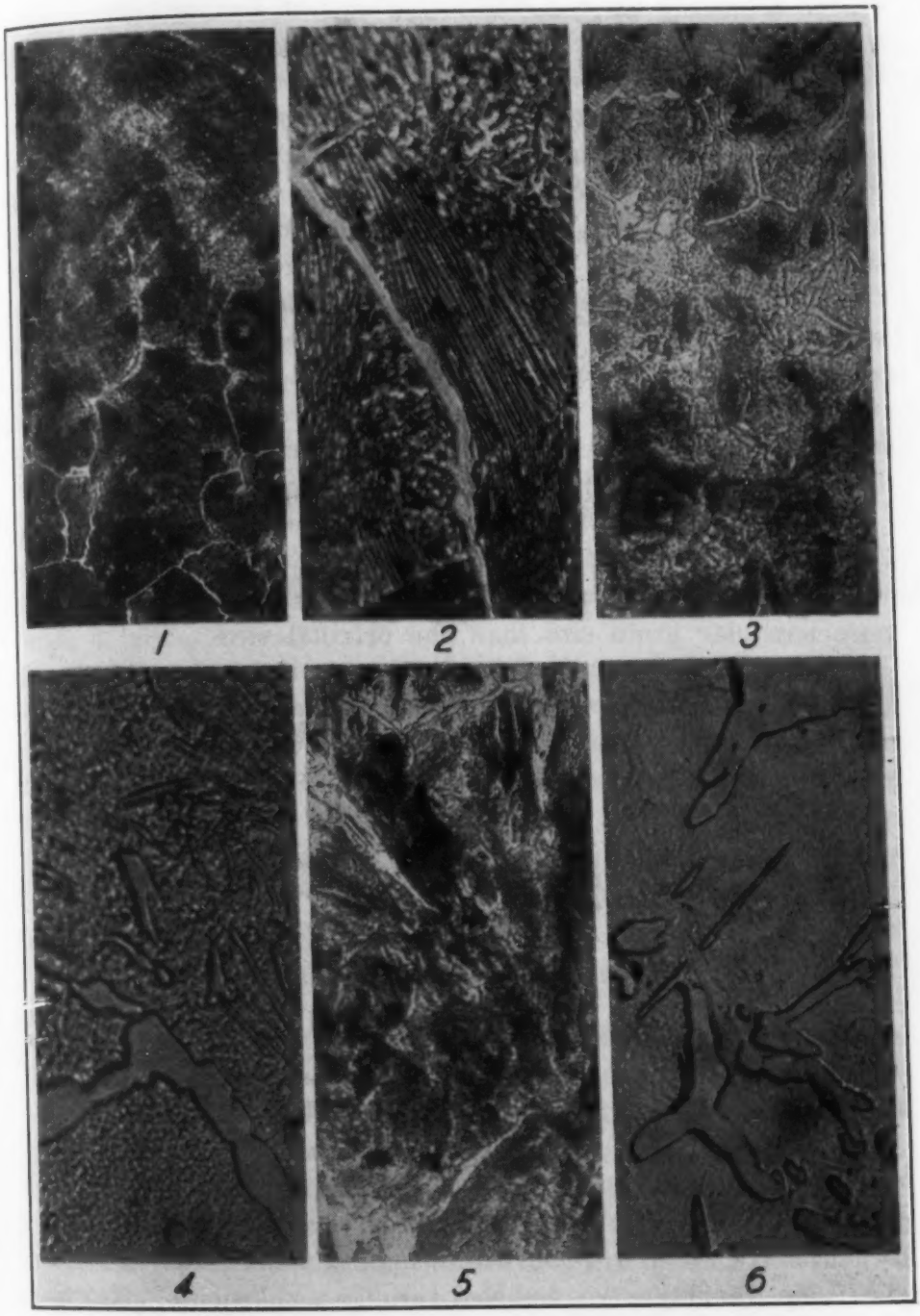


Fig. 1—Steel 77 Carburized 8 Hours at 1725 Degrees Fahr. 100 x. Fig. 2—Steel 77 Carburized 8 Hours at 1725 Degrees Fahr. 1000 x. Fig. 3—Steel 65 Carburized 8 Hours at 1725 Degrees Fahr. 100 x. Fig. 4—Steel 65 Carburized 8 Hours at 1725 Degrees Fahr. 1000 x. Fig. 5—Steel 65, Heated in Vacuo 11 Hours at 1690 Degrees Fahr. Carburized 8 Hours at 1725 Degrees Fahr. Fig. 6—Steel 65, Heated in Vacuo 11 Hours at 1690 Degrees Fahr. Carburized 8 Hours at 1725 Degrees Fahr. 1000 x.

on the normality of steel, the following test was made to attempt to remove such gases as might be dissolved in abnormal steel, thereby improving the quality.

Steel 65, which was known to be extremely abnormal, was placed in a ¾-inch quartz tube. The closed end of this tube was then put into the muffle of a small electric furnace. A vacuum pump was connected to the open end of the quartz tube and a manometer was attached to determine the pressure within the tube. It was then heated to 1690 degrees Fahr. (920 degrees Cent.) and kept at the temperature for a period of 11 hours, during which time the pressure within the tube was kept at 4 millimeters of mercury. The steel was allowed then to cool in the furnace at the reduced pressure. The only apparent change in the structure of the steel due to this treatment is a pronounced grain growth.

An examination of the steel after carburizing for 8 hours at 1725 degrees Fahr. failed to show any change in regard to normality. The steel which had been heated showed a larger and more irregular grain size than the original steel. Fig. 5 shows the heated steel after carburizing. Fig. 6 is the same specimen at a higher magnification. Both indicate extreme abnormality, and when compared to photomicrographs 3 and 4, which show the original condition of the steel, little or no difference can be seen in regard to normality. This indicates that the treatment given did not affect the carburizing property of the steel.

Effect of Heating Normal Steels in Various Gases at Carburizing Temperatures

Gas Analysis—Gases used in this investigation were a commercial product obtained in cylinders. These gases were carefully analyzed with the results shown in Table II.

Effect of Heating Normal Steel in Nitrogen—Steels 48, 64, 77, 91 and 92 were held in nitrogen under 2.5 pounds per square inch pressure above atmospheric at 1725 degrees Fahr. for a period of 10 hours. In order to remove the small amount of oxygen in the gas (0.4 per cent), it was bubbled through a solution of pyrogalol. The gas was then passed through a tube containing calcium chloride to dry it before passing it through the furnace. At the end of the 10-hour period the heat was shut off and the specimens were cooled in the furnace in an atmosphere of nitrogen. These speci-

mens were carburized for 6 hours at 1725 degrees Fahr. and cooled in the box in the furnace.

A microscopic examination of the carburized specimens showed that the steels were normal. Fig. 7 shows the case of steel 77 at 100 X. Here can be seen the normal cementitic meshwork of the hypereutectoid zone, grading into the eutectoid structure and finally into some free ferrite at the bottom of the photomicrograph.

To determine the effect of prolonged heating in a nitrogen atmosphere, a similar test was made on steels 48, 64, 77, 91, and 92. These steels were heated in nitrogen under 2.5 pounds per square

Table II

Gas Analyses

Gas	CO_2	O_2	CO	N_2 %
Nitrogen	0.0	0.4	0.0	99.6
Oxygen	0.1	96.7	1.2	2.0
Carbon dioxide	98.7	0.2	0.0	1.1

inch pressure above atmospheric at 1725 degrees Fahr. for a period of 40 hours. After this treatment the steels showed a slightly tarnished surface. A microscopic examination of the polished and etched specimens failed to show the presence of nitrides in any form. A large grain size, due no doubt to the prolonged heating, was noted.

Steels 77 and 92 were cleaned by grinding off the surface while 64 and 91 were carburized without cleaning. Steel 48 was kept in reserve for reference. The carburizing was done in the usual manner at a temperature of 1725 degrees Fahr. for a period of 8 hours. Upon being examined under the microscope, the steels were all found to have a good case with normal structure. Fig. 8 is a photomicrograph of steel 77 and is typical of the structure of the case produced by this treatment. It shows a perfectly normal structure, the grain boundaries of cementite being completely and sharply defined with no free ferrite lining them. The pearlite grains show good laminations and extend right to the cementite network. It is evident that the nitrogen had no effect on the steel with respect to normality at the temperature of this determination (1725 degrees Fahr.) even after 40 hours time.

Effect of Heating Normal Steels in Oxygen—Heating steels 48, 64, 77, 91 and 92 in oxygen for 2 hours at 1725 degrees Fahr.

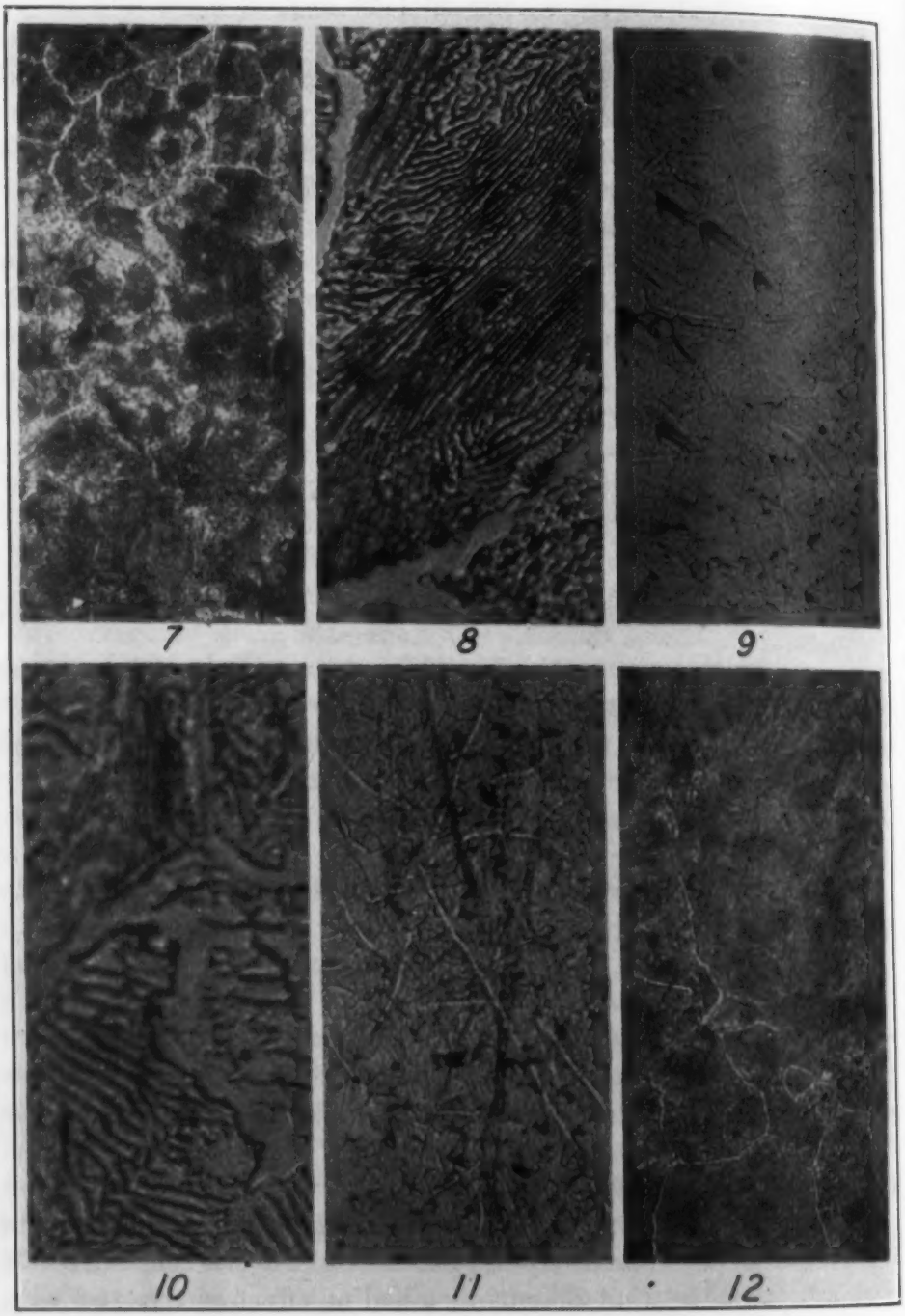


Fig. 7—Steel 77, Held in Nitrogen for 10 Hours at 1725 Degrees Fahr. Carburized 6 Hours at 1725 Degrees Fahr. 100 x. Fig. 8—Steel 77, Held in Nitrogen 40 Hours at 1725 Degrees Fahr. Carburized 8 Hours at 1725 Degrees Fahr. 1000 x. Fig. 9—Steel 91, Heated in Oxygen 2 Hours at 1725 Degrees Fahr. 100 x. Fig. 10—Steel 64, Heated in Oxygen 2 Hours at 1725 Degrees Fahr.; Carburized 6 Hours at 1725 Degrees Fahr. Fig. 11—Steel 77, Heated in Carbon Dioxide 10 Hours at 1725 Degrees Fahr. 100 x. Fig. 12—Steel 77, Heated in Carbon Dioxide 10 Hours at 1725 Degrees Fahr. 100 x.

caused so much oxidation of the surface that about one-third of each specimen was converted into oxide.

An examination of the steels after this treatment showed that in some of the specimans the pearlite near the surface had been oxidized, leaving pits or oxide inclusions in the ferrite groundmass. In some spots, however, the pearlite did not seem to have been affected. Photomicrograph Fig. 9 shows at 100 X the effect of oxygen upon the carbon content of the steel 91 which is typical. The lower right-hand portion of the field shows the original structure which consists of ferrite grains with some dark areas of pearlite. The carbon content of the steel is about 0.20 per cent. The upper left-hand portion represents the edge of the specimen, showing almost total absence of pearlite grains in the ferrite matrix. Some of the dark spots present appeared to be inclusions while others were identified as pits.

The carburizing of these specimens was done at 1725 degrees Fahr. for a period of 6 hours. The scale of oxide was removed from steels 48, 64, and 91 before they were carburized.

It was found, on examining the carburized steels, that all of the specimens showed pearlitic divorce. Those on which the scale had been left were more abnormal than the rest. The condition of these steels is illustrated by Fig. 10 which shows the hypereutectoid case of steel 64 at 1000 X. The massive condition of the ferrite and cementite is apparent.

Effect of Heating Normal Steel in Carbon Dioxide—In this determination the same procedure was followed as in the previous tests. Specimens 48, 64, 77, 91, and 92 were subjected to a temperature of 1725 degrees Fahr. in carbon dioxide gas under 2.5 pounds per square inch above atmospheric pressure for a period of 10 hours. A scale of magnetic oxide formed on the steel under this treatment, specimens 91 and 92 having more scale than the rest. Fig. 11 shows, at 100 X, the edge of one of these specimens.

The carburized specimens at first appeared to be normal, as is shown by Fig. 12 of steel 77 at 100 X. Upon further examination at higher magnification, however, a tendency toward abnormality was noted. Fig. 13 again shows the case of steel 77, but at a higher magnification. The structure of the pearlite grains is seen to be very irregular, with masses of free cementite and ferrite.

Fig. 14 was taken of the original steel 48 after carburizing, to

show the uniform hypereutectoid structure. Fig. 15 shows the same steel after it had been subjected to heating in carbon dioxide and later had been carburized. A comparison of the two photomicrographs shows the effect of the carbon dioxide treatment. Fig. 15 is characteristic of the steel subjected to heating in carbon dioxide.

The effect of prolonged heating in carbon dioxide at the carburizing temperature was found by subjecting the normal steels to the same treatment as in the first carbon dioxide test, but for a period of 35 hours. A heavy scale of magnetic oxide was formed on the steel by this treatment. The oxide formed did not seem to furnish protection against further oxidation, and, as a result, the oxidation continued to increase as the time of holding at temperature increased. All of the specimens were decarburized near the surface as is shown by the absence of pearlite in Fig. 16. This photomicrograph of steel 77 also shows the oxide formed at the grain boundaries by this treatment.

The distribution of the oxide immediately suggests that it may have been in solution at the higher temperature and then rejected to the grain boundaries during cooling. This would suggest the probability of both the austenite and the ferrite being saturated with oxide in solid solution.

Before carburizing, steels 48, 64, and 92 were thoroughly cleaned of scale by grinding, all of the scale being left on steel 91 and some on 77. The carburizing was at 1725 degrees Fahr. for 7 hours.

All of the steels of this series showed decided abnormality as is illustrated by Figs. 17, 18, 20, and 21. Fig. 17 of steel 91 at 100 X shows, at the left-hand edge, a layer of oxide scale which had been formed during the heating in carbon dioxide. To the right of that is a zone of abnormal steel, evidently caused by the dissolved or included oxides. The oxide scale may have had some influence on this carburizing reaction. Farther toward the center of the specimen the steel is seen to be normal, consisting of the usual pearlite grains surrounded by the cementite meshwork. This relation seems to show the relative rate of penetration of oxide and carbon into a steel at carburizing temperatures. It also appears that the carburizing reaction may take place through a region of abnormal steel and upon reaching an area of steel free from certain oxides may produce the characteristic normal microstructure.

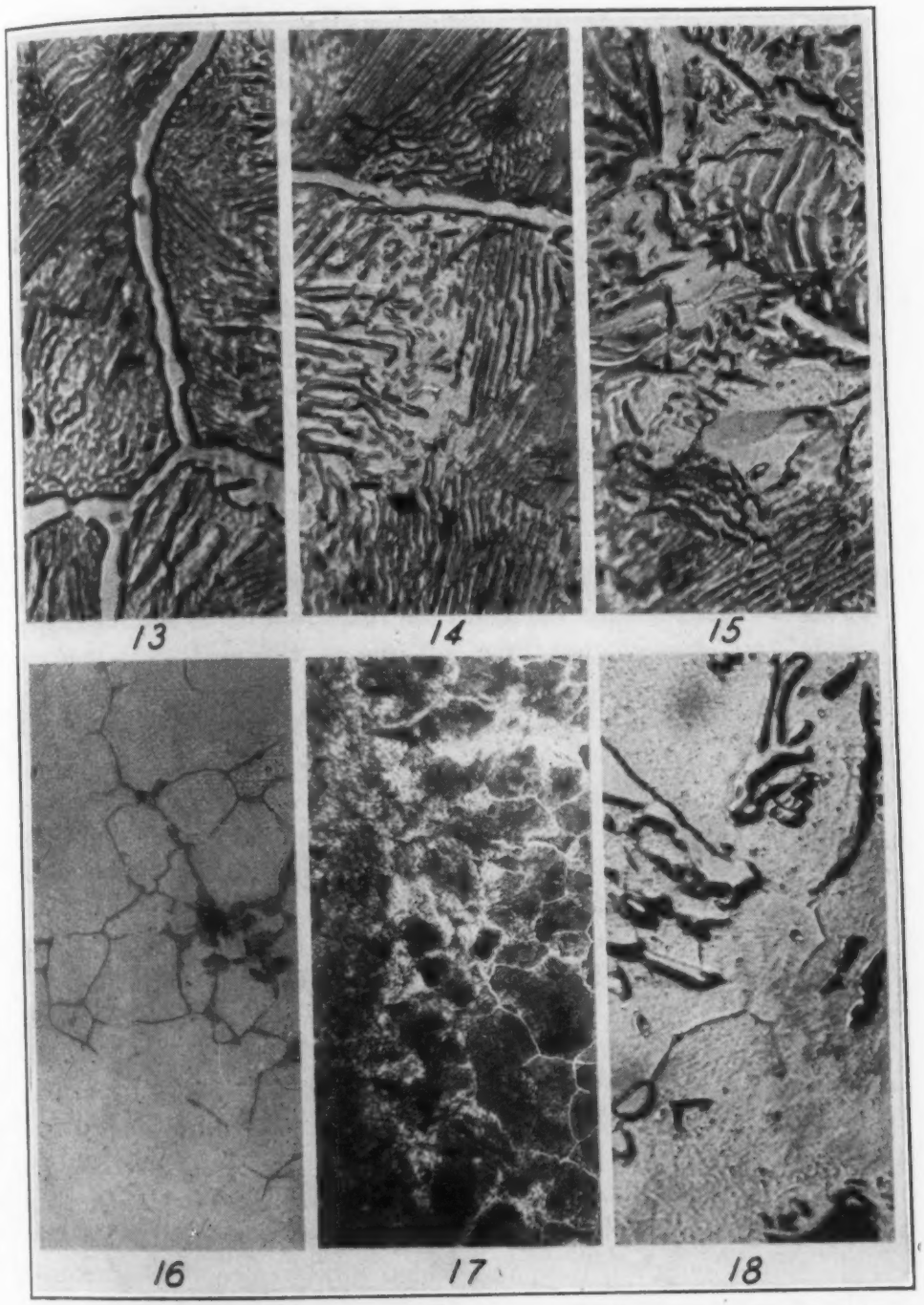


Fig. 13—Steel 77, Held in Carbon Dioxide 10 Hours at 1725 Degrees Fahr. 1000 x. Fig. 14—Steel 48, as Received. 1000 x. Fig. 15—Steel 48, Held in Carbon Dioxide 10 Hours at 1725 Degrees Fahr. Carburized 6 Hours at 1725 Degrees Fahr. Fig. 16—Steel 77, Heated 35 Hours in Carbon Dioxide at 1725 Degrees Fahr. Fig. 17—Steel 91,Heated 35 Hours in Carbon Dioxide at 1725 Degrees Fahr. Carburized 7 Hours at 1725 Degrees Fahr. 100x. Fig. 18—Same as Fig. 17. Shows the Abnormal Zone. 1000x.

Surely it has been possible in this case (Fig. 17) to produce a hypereutectoid case beyond a very abnormal zone.

The abnormal structure obtained in steel 91 is shown more in detail in Fig. 18. This photomicrograph was taken in the area immediately under the scale and shows the typical structure in which the pearlite areas are separated from the cementite by areas of free ferrite. Fig. 20 is a photomicrograph at 1000 X of steel 48. This structure appears to be slightly less abnormal than that shown in Fig. 18. This is probably due to the fact that in grinding off the scale a certain amount of the specimen which had the high oxygen content was removed.

Effect of Melting Normal and Abnormal Steels in Various Atmospheres

Introduction—In the investigation of welding in various atmospheres, it was found that abnormal steels were produced by welding in an atmosphere of nitrogen, carbon dioxide and carbon monoxide. It was suggested at that time, by one of the authors,[4a] that the abnormality was due to the compounds of iron with nitrogen, oxygen and carbon monoxide dissolved in the steel. In order to get further information it was decided to determine the effect of exposing a molten normal steel to these gases for various lengths of time and then get the effect on carburizing. Besides this, an abnormal steel was melted and cooled in vacuo in order to determine the effect on its carburizing properties.

Procedure—In order to carry out the experiments an Arsem vacuum furnace was used to heat the material. The furnace was evacuated to 3-millimeters pressure which was the minimum that could be obtained with the vacuum pump used. This pressure was maintained during the melting and cooling of the specimens melted in vacuo. For the specimens melted in various atmospheres the furnace was first evacuated to 3-millimeters pressure after which the gas was introduced from the container as described later; the steel was then melted in this atmosphere and held at temperature for the stated length of time and cooled slowly to room temperature in the given atmosphere.

Alundum crucibles were used as containers in melting the steel in these experiments, but later two melts were made using magnesite

[4a] See foot note 4.

crucibles. In all the melts made in alundum crucibles a grayish material volatilized and condensed on the cooler parts of the furnace. This volatile material was most pronounced when an atmosphere of carbon monoxide was used. This substance was analyzed qualitatively and showed aluminum present besides a black deposit

Fig. 19—Billets Obtained by Melting in Alundum Crucibles. 65, Abnormal Steel Melted and Cooled in Vacuo. 77, Normal Steel Melted and Cooled in Vacuo. 77A, Normal Steel Melted and Cooled in Nitrogen. 77B, Normal Steel Melted and Cooled in Carbon Monoxide.

similar to graphite which was insoluble in nitric, hydrochloric and sulphuric acids.

Steels Used—The steels used in these tests were No. 77 which had been found to be entirely normal on carburizing, as shown by photomicrographs Figs. 1 and 2, and No. 65 which had been found to be badly abnormal, as shown in Figs. 3 and 4.

Billets Obtained—The billets obtained in these tests are represented by those shown in the photograph Fig. 19. Billets 65 and 77 were melted and cooled in vacuo. Billet 77A was melted and cooled in an atmosphere of nitrogen. The furnace was first evacuated to 3-millimeters pressure and then the nitrogen containing 0.6 per cent oxygen was added from tanks so that the gas in the furnace was under a pressure of 5 pounds above atmospheric pressure at room temperature. The steel was melted and kept in the molten condition for 2 hours and 50 minutes; then cooled slowly in the nitrogen atmosphere. Some current was left on the furnace so as to provide for slow cooling.

Billet 77B was obtained by melting steel 77 in an atmosphere of carbon monoxide, keeping the steel molten in this atmosphere for 3 hours and then cooling slowly in the same atmosphere. The method of operation was similar to that for billet 77A except that

the pressure was atmospheric at room temperature. The carbon monoxide was made by allowing formic acid to drop into hot concentrated sulphuric acid. The gas was then passed through a strong potassium hydroxide solution and collected in a gas container over water. The moisture in the gas was then removed by passing it through concentrated sulphuric acid before it was introduced into the furnace.

It will be observed from Fig. 19 that the billet 77A shows a much more convex surface than the other specimens. Billet 77B fractured during cooling so that part of it chipped off and other cracks were visible. This brittleness of billet 77B may be attributed to the increased carbon content due to melting in an atmosphere of carbon monoxide.

The top of billet 77A was quite rough and it appeared that gas had escaped during cooling. Sections through these billets showed that 77A contained a large pipe, 65 was porous, while 77 and 77B were sound. Specimen 65 was cooled at a faster rate than 77A which may have prevented the formation of a large sink pipe.

Because of the results obtained in the microscopic examination of these specimens as melted and as carburized, it was considered advisable to make some melts using another type of crucible. Crucibles were made of magnesite brick and steels 65 and 77 melted and cooled in vacuo. The abnormal steel 65 showed a large pipe while the normal steel gave a sound billet.

Effect of Melting in Vacuo on the Microstructure of Normal and Abnormal Steels

Normal Steel—Fig. 21 shows the microstructure of the normal steel 77 after heating above the melting point in a vacuum for 2 hours and 15 minutes. The vacuum was maintained throughout the cooling to room temperature. The structure, which is at 100 X, consists of pearlite and ferrite with small round globules of nonmetallic inclusions. These inclusions had a light gray color and were not present in the steel before melting so they were very probably absorbed from the alundum crucible. The inclusions were present in quite large amounts throughout the specimen. Similar inclusions were observed in all steels melted in alundum crucibles.

Fig. 22 is the microstructure of a sample of steel 65 (abnormal) melted in vacuo in a magnesite crucible, held in the molten condition

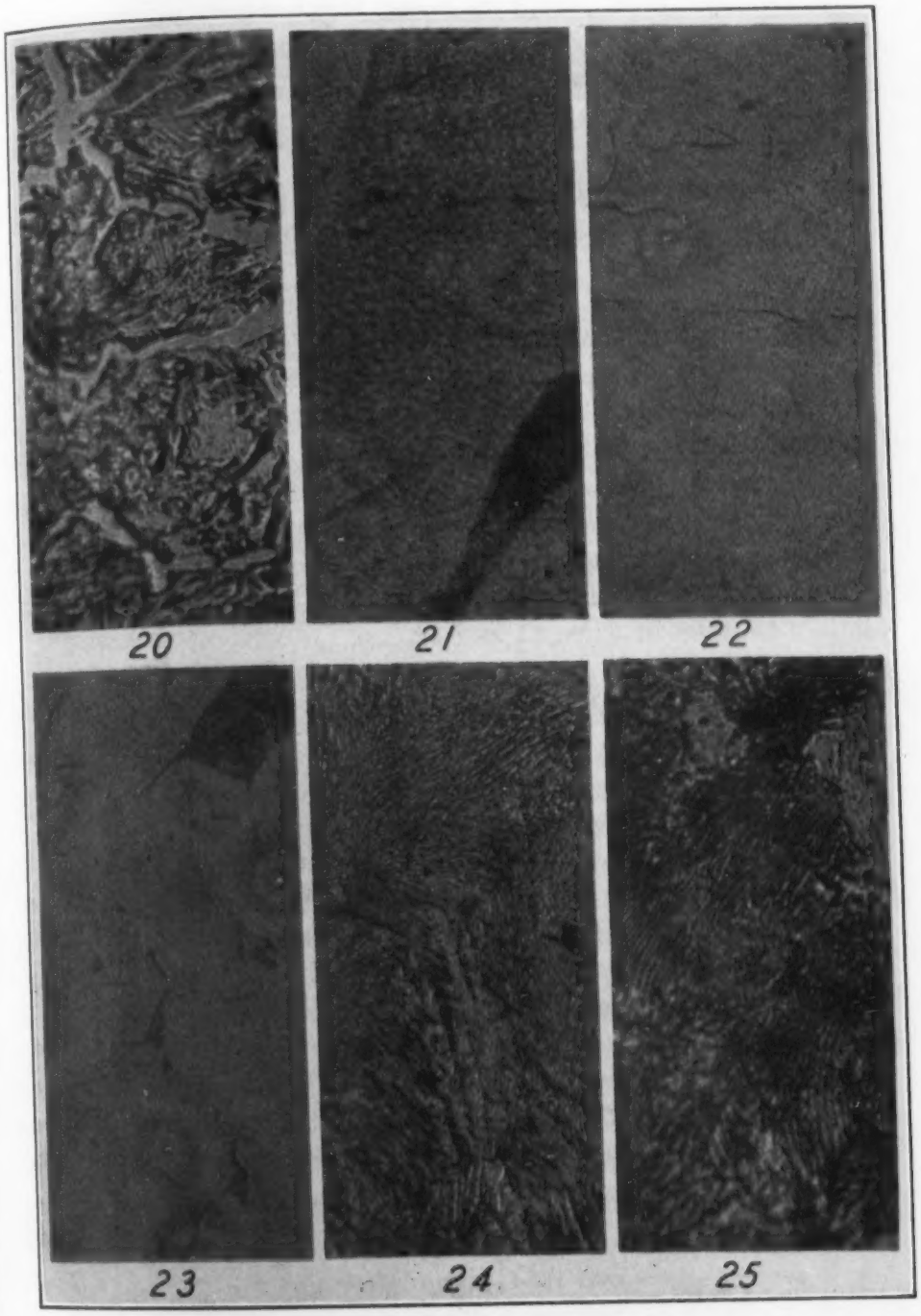


Fig. 20—Steel 48, Heated 35 Hours in Carbon Dioxide at 1725 Degrees Fahr. Carburized 7 Hours at 1725 Degrees Fahr. 1000 x. Fig. 21—Normal Steel Melted and Cooled in Vacuo in Alundum Crucible. 1000 x. Fig. 22—Abnormal Steel Melted and Cooled in Magnesite Crucible. 500 x. Fig. 23—Normal Steel Melted and Cooled in Nitrogen. 500 x. Fig. 24—Normal Steel Melted and Cooled in Carbon Monoxide. 1000 x. Fig. 25—Normal Steel Melted and Cooled in Vacuo in Alundum Crucible. Carburized 8 Hours at 1725 Degrees Fahr. 1000 x.

2 hours and then cooled to room temperature in vacuo. Non-metallic inclusions are shown as small rounded black areas. The tests were made in magnesite crucibles because, as to be discussed later, it was found that the specimens melted in alundum crucibles failed to develop the hypereutectoid zone in the carburizing tests and it was considered desirable to find out if similar results would be obtained by melting in magnesite crucibles.

Effect of Melting in Nitrogen on the Structure of Normal Steels

Fig. 23 shows the structure of the normal steel 77, obtained by keeping the molten steel for 2 hours and 50 minutes in an atmosphere of nitrogen and then cooling slowly in this atmosphere. The pressure at the beginning of the test was 5 pounds above atmospheric. The structure which is at 500 X consists of pearlite, ferrite, a needle or plate-like constituent throughout the ferrite which is most likely the nitride, and globules of non-metallic inclusions similar to those in Figs. 21 and 22.

Effect of Melting in Carbon Monoxide on the Structure of Normal Steel

Fig. 24 shows the structure of the normal steel 77 after having been kept in the molten condition in a carbon monoxide atmosphere for 3 hours and then cooled slowly in that atmosphere. The method of preparing the gas and introducing it into the furnace has previously been discussed. The structure at 1000 X shows very finely divided pearlite with a part of it being in the sorbitic state. Although not clearly indicated in this photomicrograph, there was present rounded globules of non-metallic inclusions similar to those in Figs. 21 to 23 inclusive. It should be pointed out that heating in an atmosphere of carbon monoxide carburized the specimen giving quite a high carbon content as shown in the photomicrograph.

Carburizing Tests on Steels Melted in Vacuo, in Nitrogen and in Carbon Monoxide

The steels which had been melted in vacuo or in various gases and examined microscopically were ground with an emery wheel to remove any surface dirt or scale. They were washed with alcohol to remove any grease that might be on them and then packed in

carburizing compound. The carburizing box was brought up slowly to 1725 degrees Fahr., kept at that temperature for 8 hours and then cooled slowly in the furnace to room temperature. The time was increased to 8 hours because in a previous test on part of these specimens no hypereutectoid case was produced in any of the samples after carburizing for 6 hours. A normal steel (77) in the "as received" condition was placed in the box to make certain that the carburizing procedure was correct.

Besides the specimens mentioned above, other specimens of the same material which had formerly been carburized for 6 hours were also packed into the box in order to get the effect of longer time on the case produced.

Normal Steel Melted in Vacuo—Fig. 25 shows the structure at 1000 X of the originally normal steel (77) on carburizing for 8 hours. This steel had been melted in an alundum crucible in a vacuum furnace and kept molten for 2 hours and 15 minutes. As can be seen from the photomicrograph, the structure consists of laminated pearlite and excess ferrite but no excess cemenite. Even though no hypereutectoid case was produced, the pearlite present was nicely laminated so that in this respect the steel could be considered a normal carburizing steel. It seems significant that this specimen did not give a hypereutectoid zone on carburizing 8 hours at 1725 degrees Fahr. whereas the original steel 77 had given typical structures (see Figs. 1 and 2).

Abnormal Steel Melted in Vacuo—Fig. 26 shows the structure at 1000 X of the abnormal steel (65) on carburizing for 8 hours. The structure consists of cementite particles in the ferrite with no well-formed pearlite areas. On comparing the structure with that of the specimen before melting in vacuo (Figs. 3 and 4) it can be seen that if anything the structure has become more abnormal, if the amount of well-arranged pearlite is the criterion for normality. On the other hand, the carbon content is so low there is no hypereutectoid zone and there is not the typical divorced pearlite which is probably more indicative of abnormality. This sample had been melted in an alundum crucible.

Effect of Melting in Magnesite Crucibles—Fig. 27 shows the structure obtained by the McQuaid-Ehn test on steel 65 as remelted in vacuo in a magnesite crucible. The normality has been increased by the melting treatment as there is an increase in the amount of well-arranged pearlite and a decrease in the amount of divorced

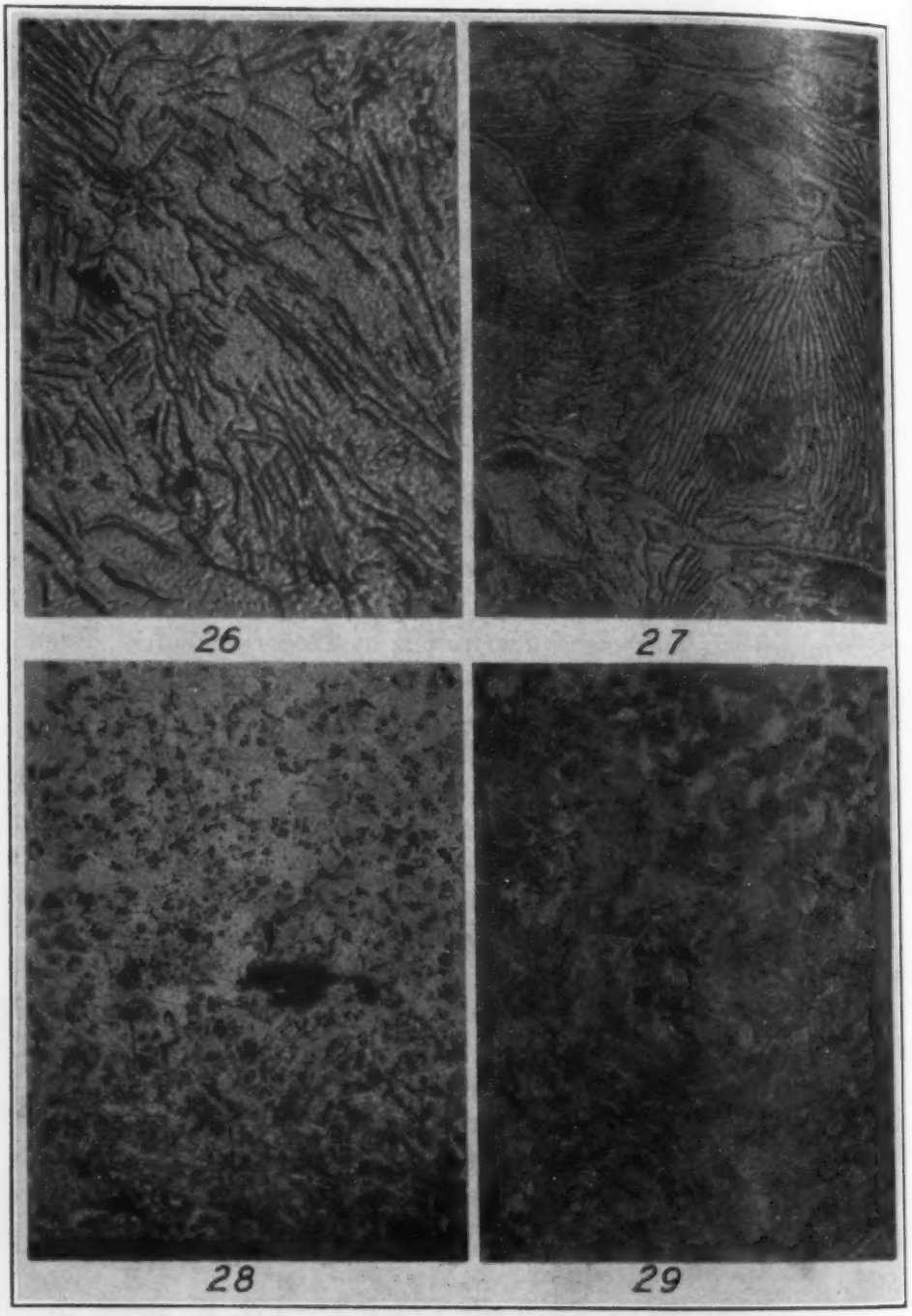


Fig. 26—Abnormal Steel Melted in Vacuo in Alundum Crucible and Carburized 8 Hours at 1725 Degrees Fahr. 1000 x. Fig. 27—Carburizing Test on Abnormal Steel 65 Remelted and Cooled in Vacuo in Magnesite Crucible. 500 x. Fig. 28—Carburizing Test on Normal Steel Melted and Cooled in Nitrogen in Alundum Crucible. 50 x. Fig. 29—Carburizing Test on Normal Steel Melted and Cooled in Carbon Monoxide. 100 x.

pearlite. Melting in a magnesite crucible in vacuo greatly increased the normality and at the same time gave a steel in which a hypereutectoid zone could be obtained.

Melting normal steel (77) in vacuo in a magnesite crucible gave a steel which when carburized produced a structure identical to that shown in Fig. 27. Thus it appears that melting a normal steel in either alundum or magnesite crucibles produces an abnormality tendency.

Normal Steel Melted in Nitrogen—Fig. 28 shows the structure at 50 X of the normal steel (77) on carburizing for 8 hours after keeping the molten steel in an atmosphere of nitrogen for 2 hours and 50 minutes. The dark areas are the pearlite while the light areas are the ferrite. The black spots are due to blowholes in the specimen. The edge of the specimen is on the left-hand side so that the depth of case can be readily seen. In no part of the specimen was the carbon content as high as 0.90 per cent.

Normal Steel Melted in Carbon Monoxide—Fig. 29 shows the structure at 100 X of the normal steel (77) on carburizing for 8 hours after keeping the molten steel in an atmosphere of carbon monoxide for 3 hours. The left-hand side shows the edge of the specimen and is approximately of eutectoid composition. In no part of the specimen could a hypereutectoid steel be found. The carbon content in this steel was higher than in any of the other steels due most likely to the high carbon content before carburizing. The pearlite present showed at higher magnification a laminated structure and in this respect it could be classified as a normal carburizing steel. The steel (77) which was put into the pot to check the carburizing procedure showed a hypereutectoid case indicating that the carburizing was done properly.

The specimens carburized for 14 hours showed structures similar to those described for the specimens carburized for 8 hours. In none of them was there a hypereutectoid case present even after carburizing for 14 hours.

The difficulty of carburizing the specimens was probably due to the aluminum oxide present in the steel. At the time it was thought that it might be possible to obtain better results by using a baked alundum crucible instead of the one that was used, but later tests showed exactly similar results when baked alundum crucibles were used.

Effect of Heating Normal Steels in Contact with Various Sonims

Since thus far during this work it was found that abnormal steels were produced by heating normal steels in the various gases only when those gases formed oxides, it appeared that the presence of oxides was a determining factor, and the present part of the work was concentrated on that part of the investigation. In this phase of the work the effect of heating oxides in contact with normal steels at the carburizing temperature was studied.

In Table III is given the sonims used in the investigation together with the letters used in the identification of specimens.

Table III

Sonims Used in the Investigation

Series	Sonim	Remarks
A	Fe_3O_4	Magnetic mill scale.
B	Fe_2O_3	C. P.
C	Slag	Open-hearth ingot iron.
D	Al_2O_3	C. P.
E	Alundum	Alundum crucible.

Twenty-five pieces of normal steel (77), 3 inches long, were cut from the ⅝-inch round stock and a ¼-inch hole drilled lengthwise through the center of each to within ¼-inch of the end. The holes were then tapped so as to take a ¼-inch stove bolt as a means of sealing the cavity. The cylinders were cleaned on outside by grinding off the surface, and were washed inside with gasoline rinsed with alcohol. Five of these cylinders were packed with each of the oxides, which had been pulverized, and the openings were sealed by screwing into them ¼-inch stove bolts. In order to prevent surface oxidation of the specimens as much as possible, they were given a ¼-inch coating of material made up as follows:

	Per Cent
Fireclay	66
Water glass	20
NaCl	7
Sil-o-cel	7

Made up with water to a plastic mixture.

This coating was first dried in air and then baked in an electric oven for 5 hours at 150 degrees Cent.

The entire lot of specimens was placed in an electric muffle furnace and heated to 1725 degrees Fahr. At the end of 4 hours at temperature, one specimen of each series was removed from the furnace and allowed to cool in the air. In like manner, specimens

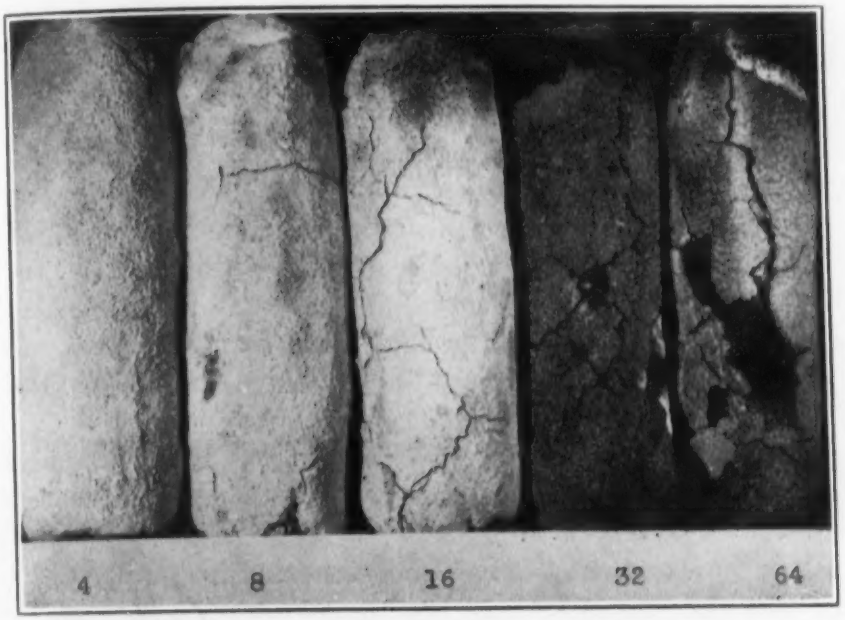


Fig. 30—Specimens Heated in Contact with Sonims.

of each series were removed at the end of 8, 16, 32, and 64 hours at the carburizing temperature.

It was found that the protective coating cracked rather badly, especially on prolonged heating, so that it was not as effective a protection as was desired. Fig. 30 shows one series of specimens as they appeared upon removal from the furnace. The darkening of the coating on long heating is due to the formation of oxide.

After the cylinders were cleaned of the coating, the sealed ends were cut off and a section was cut from each of the specimens. The oxides were completely removed and all the surface scale ground off. The specimens were carburized for 8 hours at 1725 degrees Fahr. and allowed to cool in the box in the furnace.

Table IV shows what a microscopic examination revealed in regard to the normality of the steel adjacent to the cavities which had been filled with the sonims.

Table IV
Microscopic Examination of Specimens

Time Heated at 1725° F., Hours	SPECIMEN MARKS AND SONIMS USED A (Fe_3O_4)	B (Fe_2O_3)	C (Slag)	D (Al_2O_3)	E (Alundum)
4	Abn.	Nor.	Nor.	V. S. Abn.	S. Abn.
8	Abn.	Abn.	S. Abn.	Abn.	Abn.
16	Abn.	Abn.	Abn.	Abn.	Abn.
32	Abn.	Abn.	Abn.	Abn.	Abn.
64	Abn.	Abn.	Abn.	Abn.	Abn.

NOTE: (S. Abn.) = Slightly Abnormal.
(V. S. Abn.) = Very Slightly Abnormal.

Discussion of Results—In each case the depth of the abnormal zone increased with the time of heating. Its thickness in the specimens heated for 64 hours averaged about 0.5 millimeters and decreased to a narrow band in some of the 4-hour specimens, and disappeared completely in some of the specimens as indicated in Table IV.

Two types of abnormal structure were observed, one of which is illustrated by the photomicrographs of the specimens heated in contact with magnetic iron oxide, Fe_3O_4, and the other type of which is represented by the specimens heated in contact with alundum. The abnormal structure produced by heating in contact with Fe_3O_4 four hours at 1725 degrees Fahr. is shown in Fig. 31 at a magnification of 1000 X.

The greater depth of penetration obtained by heating in contact with magnetic iron oxide for 64 hours is shown in Fig. 32, while the characteristic abnormal structure obtained under those conditions is shown in Fig. 33. These types of abnormality as produced by heating in contact with magnetic iron oxide are more nearly typical of those which have been reported in the literature and they are also typical of most of the structures reported in this investigation.

This work has already shown that another type of abnormality was observed in the normal steels which had been melted in vacuo and in various gases, particularly in alundum crucibles. This type of abnormality is again found in our specimens which were heated in contact with alundum at carburizing temperatures. The general characteristics of the carburized zone are shown in Fig. 34. This structure is shown at a higher magnification in Fig. 35. It will be

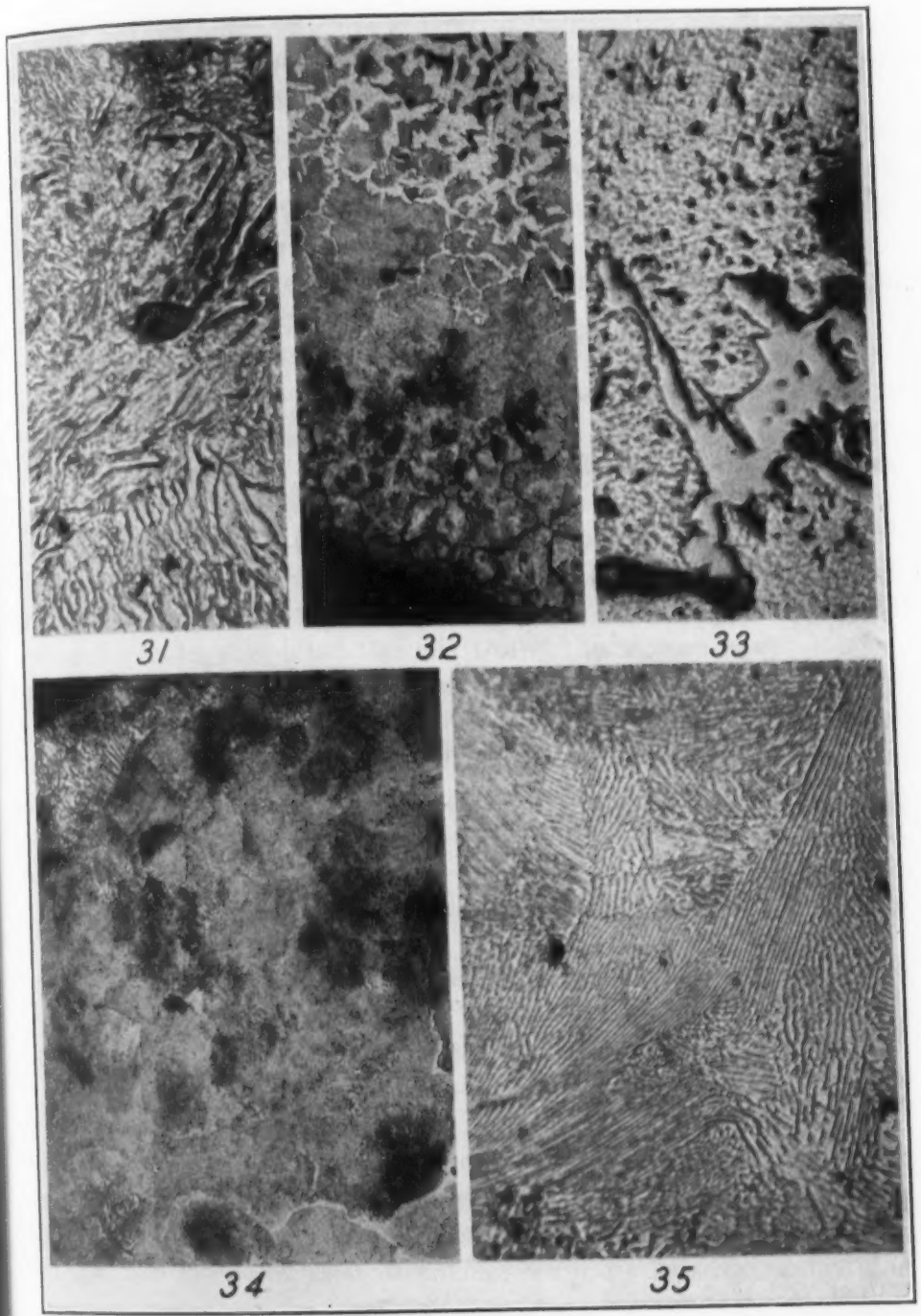


Fig. 31—Steel 77, Heated in Contact with Fe_3O_4 for 4 Hours at 1725 Degrees Fahr. 1000 x. Fig. 32—Steel 77, Heated 64 Hours in Contact with Fe_3O_4 at 1725 Degrees Fahr. 50 x. Fig. 33—Steel 77, Heated 64 Hours in Contact with Fe_3O_4 at 1725 Degrees Fahr. 1000 x. Fig. 34—Steel 77, Heated 32 Hours in Contact with Alundum at 1725 Degrees Fahr. Carburized. 100 x. Fig. 35—Same as Fig. 24. 1000 x.

observed that a rather well-formed pearlite is obtained, but there is no hypereutectoid zone; neither is there divorced pearlite.

The structures obtained in the carburizing tests on the specimens which had been heated in contact with iron oxide, and those which had been heated in contact with aluminum oxide, suggest an important relation in connection with the influence of these oxides on the direction of the Acm line. They seem to indicate that iron oxide shifts the eutectoid point toward the pure iron side of the diagram, and that the amount of this shifting may be to 0.45 per cent carbon or even lower. They also indicate that at elevated temperatures the Acm line in contact with oxides approaches a normal position. This conclusion is apparently rather well established by other investigators who found that the carbon content of the hypereutectoid zone in abnormal steel is almost identical with that of the normal steel. The fact that we have been unable to produce a hypereutectoid zone in the case of the steels containing aluminum oxide indicates that this line runs almost perpendicular from the eutectoid point and possibly runs somewhat toward the left-hand side of the diagram at higher temperatures. This relation will be taken up somewhat more in detail in connection with theoretical discussion. An important relation between the rate of travel of sonims in austenite at carburizing temperatures as compared with the rate of travel of the carbide has been found in this investigation.

X-ray Analysis of Normal and Abnormal Steels

Materials Used—For this study steels Nos. 65 and 77 were chosen as typical abnormal and normal steels respectively. The other materials analyzed are given in Table V which is a summary of materials used and results obtained.

The surfaces of the bars or billets from which samples were taken were first ground off to remove all foreign material. A representative sample was obtained in each case by taking filings from the entire cross section of the bar. The filings were then reduced in size by means of an agate mortar to pass 200-mesh silk bolting cloth.

The specimen tubes were divided into two compartments by means of a small plug of cotton. One of the compartments was filled with sodium chloride which was used as a reference substance, and the sample of steel, diluted with an equal amount of starch, was

placed in the other. The tubes were sealed at the ends by cotton plugs and sealing wax. The X-ray diffraction apparatus used was a Type VWC, Form B, devised by Hull.

The specimens were exposed to X-rays for 74 hours. Good patterns were obtained for the steels as well as for the sodium chloride. The corrected data[5] resulting from these determinations for steels 77 and 65 are given in Table VI.

Table V

Data from X-Ray Analyses of Normal and Abnormal Steels

Steel No.	Description of Steel	Ehn Test	Unit Parameter
77	S. A. E. 1020, as received	Normal	2.855Å
60	Wrought iron, double refined	Abnormal	2.868
65	Ingot iron, as received	Abnormal	2.864
77	S. A. E. 1020, melted in vacuo[1]	Normal pearlite but no hypereutectoid zone	2.860
65	Ingot iron, melted in vacuo[2]	Normal pearlite but no hypereutectoid zone	2.868
77	S. A. E. 1020, melted in vacuo[2]	Normal pearlite but no hypereutectoid zone	2.865
	Electrolytic iron[3]	Slightly abnormal	2.858
	Electric weld[4]	Abnormal	2.855-2.861

[1]Melted in vacuo in soft alundum crucible, kept molten 2½ hours and cooled in vacuo.
[2]Melted in vacuo in hard alundum crucible, kept molten 2½ hours and cooled in vacuo.
[3]Melted in vacuo by Yensen, then reheated and forged into ⅝-inch rounds.
[4]Weld deposited by electric arc in air.

Table VI

X-Ray Diffraction Data for Normal and Abnormal Steels

Plane (Miller Indices)	INTER-PLANAR DISTANCES IN ANGSTROM UNITS (Å) Steel 77	Steel 65	Difference*
110	2.025	2.030	0.005
100	1.427	1.431	0.004
211	1.166	1.168	0.002
110	1.009	1.014	0.005
310	0.902	0.905	0.003
111	0.822	0.824	0.002
321	0.761	0.764	0.003

*Difference is the increase of the abnormal over the normal inter-planar distance.
Angstrom Unit (Å) = 10^{-8} cm.

Discussion—It seems particularly significant that all of the abnormal steels, that is those which gave abnormal microstructures

[5]Method of calculating data is given more in detail in TRANSACTIONS, American Society for Steel Treating, Vol. XI, pp. 959-974 (1927).

after carburizing, showed an increased unit parameter, the magnitude of the increase ranging from 0.005 to 0.013 Å. The results obtained from the X-ray analysis of a weld, that is metal deposited by an electric arc in air, are somewhat unusual. The lines on the film are spread and some of the first lines were almost double lines. As a result the readings were erratic. If one part of the line was taken for calculation, a unit parameter of 2.855 Å was obtained which would correspond to the value obtained for normal steel; if another part of the line was read, a unit parameter of 2.861 was obtained which would correspond to the value obtained with some of the abnormal steels. This suggests that the weld is made up of non-uniform material, some parts of which were normal and other parts of which were abnormal due to the absorption of oxide.

Abnormality of Electric Welds

Welds in Various Atmospheres—An earlier investigation[6] reported from this laboratory has shown that metal deposited by an electric arc in atmospheres of carbon dioxide, carbon monoxide, nitrogen, and air gave abnormal structures upon carburizing, while metal deposited in an atmosphere of helium gave an entirely normal structure in the carburizing test.

Effect of Alloying Elements on Electric Welds—Preliminary tests with a few alloy steel welding rods have been made. The deposited metal, after being subjected to the McQuaid-Ehn carburizing test, gave the following results for metals deposited by the electric arc in air.

Nickel steel rod gave very decidedly abnormal structures. The same was observed in the case of steel rod containing small amounts of molybdenum. The welding rod containing titanium gave an abnormal structure principally in regard to the absence of the hypereutectoid zone. In other words, it appears that titanium gives a structure similar to that obtained by melting steel in an alundum crucible.

Theoretical Discussion

Purpose—The following theoretical discussion has for its purpose proposing a mechanism for the formation of the abnormal structure observed in certain steels when subjected to the McQuaid-

[6]See foot note 1.

Ehn carburizing test. We have, at the present time, certain experimental evidence for the theories proposed, but in some cases at least the theory is not completely established.

Formation of Abnormal Structure—Fig. 36 has been drawn to assist in the discussion and to represent what is believed to be an approximation of the diagram based on experimental work to date.

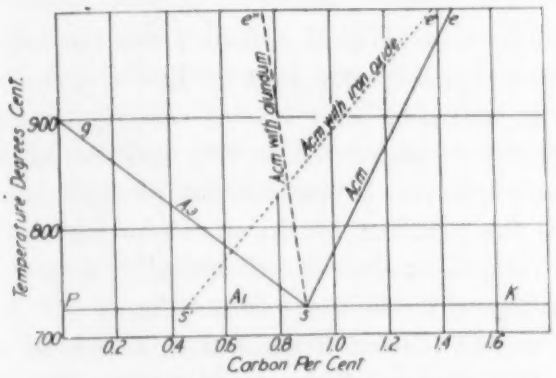


Fig. 36—Diagram to Illustrate the Probable Mechanism of the Formation of the Microstructure in Abnormal Carburizing Steels.

The metastable system as generally accepted at the present time is represented by the solid lines while the diagrams as modified by various materials which cause abnormal structures are indicated by the dotted lines. The lines s′-e′ is intended to show the influence of iron oxide on the Acm line and on the eutectoid point. The line s-e″is intended to indicate the influence of oxide in contact with aluminum or aluminum oxide on the Acm line.

For the purpose of illustration, suppose we assume a steel which gives an abnormal structure and which was carburized to a hypereutectoid zone of 1.2 per cent carbon. It will be noted that there is comparatively little difference in the position of the two lines (s-e and s′-e′) at such a temperature, approximately 950 degrees Cent. The slow diffusion of iron oxide in the austenite, as indicated by our tests, would suggest that particles of the oxide would go into solution in the austenite but would diffuse over a comparatively small area. This comparatively small area would be the region in which the Acm line would be first reached on cooling. It is noticeable in many photomicrographs of abnormal steels that impurities frequently appear in or adjacent to the massive cementite areas. These impurities may have separated out on cooling or they may not have gone completely into solution at the car-

burizing temperature. This furnishes a mechanism whereby the cementite separates out at a comparatively high temperature. This high temperature (s′-e′) will be favorable for the coalescence of the precipitated cementite into large masses. As cooling continues, the cementite particularly in those areas containing a large amount of oxide, may be expected to continue to separate out along the line s′-e′.

It seems important then to consider the conditions at a temperature just above the intersection of line s′-e′ with the line g-s or A_3. Under an infinitely slow rate of cooling we may expect the simultaneous precipitation of the ferrite and cementite phases, but there have been numerous investigations to show that the rate of cooling modifies the position of the normal eutectoid point in the metastable system, and as the rate of cooling increases the eutectoid point is shifted towards the pure iron side of the diagram. We may, therefore, expect a certain amount of supercooling before the formation of ferrite grains. This would mean a further separation of cementite producing a supercooled system with respect to the formation of ferrite. It is proposed that, under this condition, the system may be cooled down to some point such as s′ before the formation of ferrite actually begins.

There is another relation which should be considered and that is the influence of the predominant partner, as has been discussed quite extensively in the literature; that is, the presence of cementite particles as a separate phase would undoubtedly be favorable to the continued precipitation of the cementite and the formation of a supercooled and supersaturated austenite solid solution with reference to the ferrite phase. This condition then would seem to be favorable to the formation of massive ferrite adjacent to the massive cementite, supposing that at some temperature such as s′ ferrite crystals begin to form in a system which is considerably supercooled. Ferrite formed under such conditions may be expected to be very fine grained and therefore will have an unusual hardness such as was pointed out by Gat in his paper read at the sectional meeting of the society in Washington, January, 1927.

The proposed mechanism would then require that after the formation of massive ferrite the remaining austenite would in some cases give a rather well formed lamellar pearlite, depending somewhat upon the oxygen content of the austenite. If the oxygen content of the austenite should be comparatively high, then the re-

sulting pearlite should be of lower carbon content than is usually associated with the normal pearlite. It may be that the point indicated in the diagram as s′ should be drawn considerably closer to the pure iron side of the diagram.

Our experimental work to date indicates that the influence of aluminum oxide in contact with steel is decidedly different from iron oxide. In the case of aluminum oxide we have not been able to obtain a hypereutectoid case even after 14 hours carburizing. It is therefore believed that the Acm line runs somewhat in the direction indicated by the line s-e″. This would limit the solubility of carbon in the austenite at elevated temperatures and would be likely to show a slightly hypoeutectoid structure as we have found in our experiments.

Influence of Oxides on the Eutectoid Point—A brief survey of the literature will show that there has been the greatest lack of agreement on the eutectoid composition in steel. For example, we have just recently examined a considerable number of steels which contained an average of about 0.70 per cent carbon and an average manganese content of about 0.75 per cent and other elements normal by actual analysis, and they show practically a eutectoid structure as normalized. Many of these steels showed abnormal tendencies in the carburizing tests. A review of such investigations as that reported by Hayes and Wakefield (TRANSACTIONS, American Society for Steel Treating, Vol. X, p. 214) and the discussion by the various authors suggests that their lack of agreement on the eutectoid composition may have been largely attributable to the relative amounts of oxygen contained in the samples under investigation.

Gat's Eutectoid Phase—Gat in his paper presented at the Washington Sectional meeting of the society, proposed the term "eutectoid alloy" for the massive ferrite observed in abnormal carburizing steels. It is believed by the authors that the above theoretical discussion suggests the cause of the hardness in this massive ferrite as observed by Gat. According to our usual conception of the eutectoid alloy, this microstructure would be expected to represent the composition of the austenite at or just above the eutectoid temperature. The microstructure observed by Gat on deep etching can be produced in almost any ferrite, and it is very doubtful if he is justified in considering the material as a duplex structure. If the proposed mechanism of the formation of the

massive ferrite is correct, then it would provide for a very fine-grained ferrite which would doubtless give a material of greater hardness. Furthermore, the indications are that this ferrite contains oxide or oxygen in solution and this factor should give additional hardness. If this structure by further research is shown to be something different from what we have usually observed, the indications are at the present time that this difference will be due to oxygen and a more appropriate name than "eutectoid alloy" would seem to be "ferroxite." All students of metallography will undoubtedly agree that we have more microconstituents to remember now than is possible and they will doubtless be opposed to adding any new ones to the list.

Discussion of Abnormality of Rimming Steel—It seems at the present time that X-ray analysis and oxygen determinations may throw considerable light on the cause of the peculiar macrostructures observed in certain rimmed steels. For example, Epstein and Rawdon in their paper (Fig. 4) presented at the sectional meeting of the society held in Washington, show a rimmed steel in which the outside is normal on carburizing while the interior is abnormal on carburizing. It seems an interesting coincidence that a paper by Rawdon, Hidnert and Tucker (TRANSACTIONS, American Society for Steel Treating, Vol. X, p. 233-256), reported on page 250 the oxygen determinations of center and edge of a bar of open-hearth steel in which they found the oxygen content in determination 4 for the center of the bar nearly three times as great as in determination 5 cut from the edge of the same bar. This relation suggests that some of the disagreement with reference to the relation of oxygen content to carburizing abnormality in steel may have been due to the way in which the samples were taken for the oxygen determinations. At any rate it shows that oxygen determinations should be made on that particular section of the bar which is to be used in the carburizing test.

SUMMARY AND CONCLUSIONS

1. Heating abnormal steel in a vacuum at the carburizing temperature has no apparent effect in regard to its normality.

2. Heating a normal steel in nitrogen at 1725 degrees Fahr. did not change its carburizing properties. This may be due to the nitrides not being formed by heating steel in nitrogen gas at this temperature.

3. Heating normal steels in oxygen at 1725 degrees Fahr. causes the steel to take on abnormal carburizing characteristics. This is believed to be due to the formation and solution of the oxides in the steel.

4. Heating normal steel in carbon dioxide at 1725 degrees Fahr. produces an abnormal steel. This is thought to be due to the oxidizing action of carbon dioxide.

5. The effect of heating normal steels in contact with various oxides at the carburizing temperature, is to cause solution of the oxides in the austenite and thereby to produce abnormal steels. The depth of penetration of oxides is proportional to the time of heating, as also to a great extent is the degree of coalescence of cementite in the carburized steel or the abnormality of the steel.

Of the various sonims studied, ferric oxide (Fe_2O_3) seems to show the most rapid penetration and to produce the most abnormal steel for a given time of heating at the temperature studied. This relation may be due to its higher oxygen content and the greater ease with which it will give up some of its oxygen.

The rate of penetration of the oxide or oxygen, as determined by the formation of an abnormal carburizing zone, is exceedingly slow as compared with carbon penetration, for example. The carbon is able to penetrate through a surface of abnormal steel and then produce a normal hypereutectoid zone. The more rapid penetration of the carbon as compared with that of the oxygen is probably attributable mostly to the relative affinities of oxygen and carbon for iron, or to state the same relation in another way, the relative stabilities of iron carbide and iron oxide compounds. In addition, the carbon atom is smaller than the oxygen atom and should for that reason diffuse more rapidly.

6. X-ray analyses show that in the abnormal steel the lattice dimensions are greater than those of normal steel, indicating the presence of foreign material, probably oxide, in solid solution in the ferrite. Probably the mechanism of this phenomenon is more correctly stated by saying that the oxygen goes into the iron space lattice and there exercises some bonding valences with the adjacent iron atoms.

7. Melting an abnormal steel in vacuo in alundum crucibles considerably decreased the abnormal tendency as regards massive cementite but still gave a steel which would not produce a hyper-

eutectoid zone on carburizing and the pearlite was coarsely laminated.

8. Melting a normal steel in vacuo in an alundum crucible produced steel that showed abnormal characteristics with regard to the absence of hypereutectoid zone.

9. Melting an abnormal steel in vacuo in a magnesite crucible decreased its abnormal tendencies but did not produce an entirely normal structure.

10. Melting a normal steel in a magnesite crucible in vacuo produced a steel with abnormal tendencies, but a steel which would show a hypereutectoid zone on carburizing.

11. Normal steel melted in nitrogen in an alundum crucible gave steel which showed abnormal on carburizing both as to the character of the pearlite and the absence of hypereutectoid zone.

12. Melting normal steel in carbon monoxide in an alundum crucible gave a fine-grained eutectoid structure in which the pearlite was rather abnormal and showed no hypereutectoid zone.

13. A diagram has been drawn to illustrate the probable mechanism of the formation of the structure in abnormal carburizing steel. This diagram is in agreement with the information available at the present time so far as the authors know, but evidently will require further investigation.

Acknowledgment

The authors are indebted to Dr. R. L. Dowdell for some assistance in this investigation and to Miss C. H. Green, assistant in metallography, for valuable assistance in the photographic work and in the preparation of the manuscript.

DISCUSSION

Written Discussion: By J. L. Gregg, Western Electric Company, Chicago.

Is it not possible that the "abnormal" hypereutectoid structure produced after carburization is the normal structure for pure iron-carbon alloys cooled at the rate generally used in testing steel by the McQuaid-Ehn test, and that the structure in which no free ferrite is present in the case results from something other than pure iron inhibiting the diffusion of carbon, or cementite, to form the massive cementite? This is partially upheld by carburizing tests at these laboratories on unannealed electrolytic iron and vacuum-melted electrolytic iron of such a high purity as to

have a maximum permeability several times that of ordinary iron. Both of these irons of high purity were very abnormal in that very little pearlite was present in the hypereutectoid zone. These results are somewhat in disagreement with the results reported in the paper under discussion, although they are in agreement with other reported results.

It is my opinion that abnormality (as indicated by the hypereutectoid zone) is much more readily explained by diffusion after pearlite has once been formed than by a shifting of the Acm line indicated in Fig. 36. With this in mind, a study of steel cooled slowly to just under Ar_1 and quenched would appear to be of interest.

Written Discussion: By W. J. Merten, Westinghouse Electric & Manufacturing Company, East Pittsburgh.

After reading the paper, the impression obtained was that the real practical value of the paper centers around the results and confirmatory information obtained from the experiments regarding the factors influencing cementation of iron or steel with carbon, or, in other words, what are the conditions during carburizing that result in an irregular and hypoeutectoid carbon case. A title to this effect for the paper, I believe, would have been more appropriate and probably would have resulted in diverting these investigations to the real problem of development and advancement of uniform cementation of steel.

From the viewpoint of a study on normal and abnormal steel, the paper adds simply some more laboratory data and theoretical dissertation to the maze of written matter on the subject. It is not even surprising that the authors find still another type of abnormality (see page 982) after passing a good bar of steel through their vacuum remelting process.

However, such information as the effect of alundum and other oxides in contact with steel at carburizing temperatures upon the cementation reaction is of immense practical value, since it is well known that luting and sealing of carburizing boxes is done with refractory clays containing these compounds and very often little care is exercised in keeping the carburizing compound free from this clay, in fact, for partial carburizing, the portion desired soft after case hardening of parts are thickly coated with refractory clays and refractory cement mixtures containing these objectionable oxides, and they are packed right into the container with carburizing compounds.

Written Discussion: By S. Epstein, associate metallurgist, Bureau of Standards, Washington, D. C.

The heating and melting treatments of normal and abnormal steel in various atmospheres are an interesting addition to our data on the problem and present a fruitful means of attack. By heating or melting steel under oxidizing conditions, abnormal structures were obtained. We should be careful, however, not to make the inference, as the authors have done, particularly in the discussion of their X-ray analyses, that such laboratory products showing abnormal structures are the same as, or are typical of, commercial abnormal steel. The carburizing test is a sensitive

means of dectecting various irregularities in composition or melting procedure. A steel with excessive phosphorus content, for instance, has an abnormal structure. It does not follow that a steel high in phosphorus is a typical abnormal steel, for commercial abnormal steel is usually not high in phosphorus. In the same way, a steel with excessive oxygen content has an abnormal structure. Such a steel, however, cannot be regarded as a typical abnormal steel, for oxygen analyses have shown that commercial abnormal steel is usually not high in oxygen, although, of course, some commercial abnormal steels do have a high content. The various means by which abnormal structures may be obtained are interesting clues on the problem, but no one of them it seems has offered the full explanation of abnormality to commercial steel.

The authors have omitted to treat their specimens in hydrogen. Annealing in hydrogen has been found by the writer to change the structure of some steels from abnormal to normal. This effect was confined

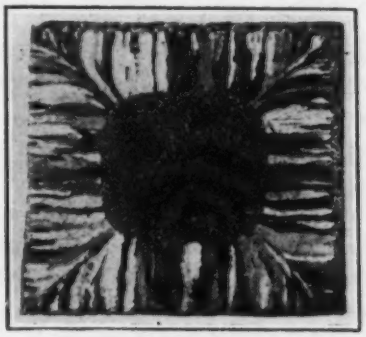
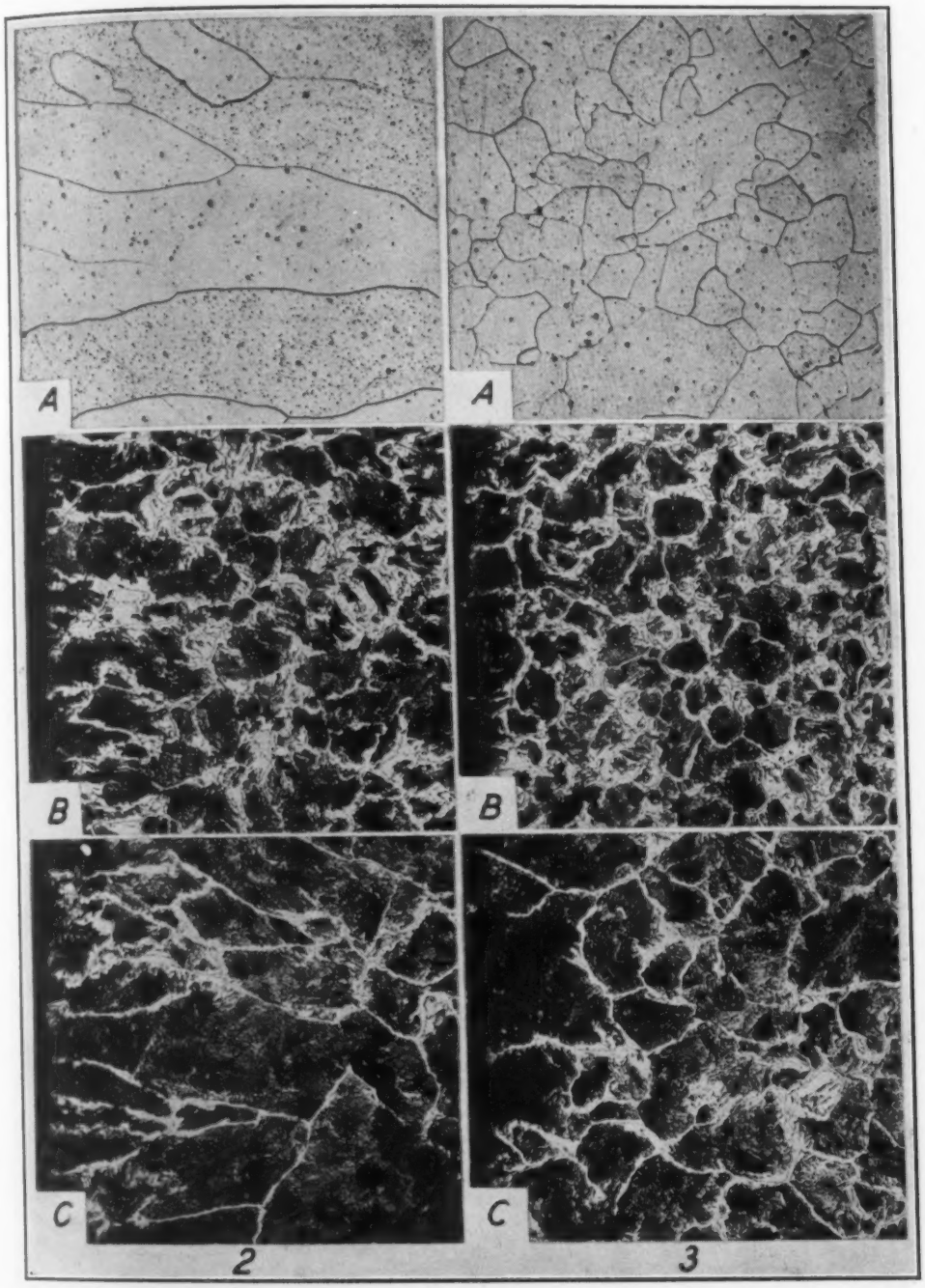


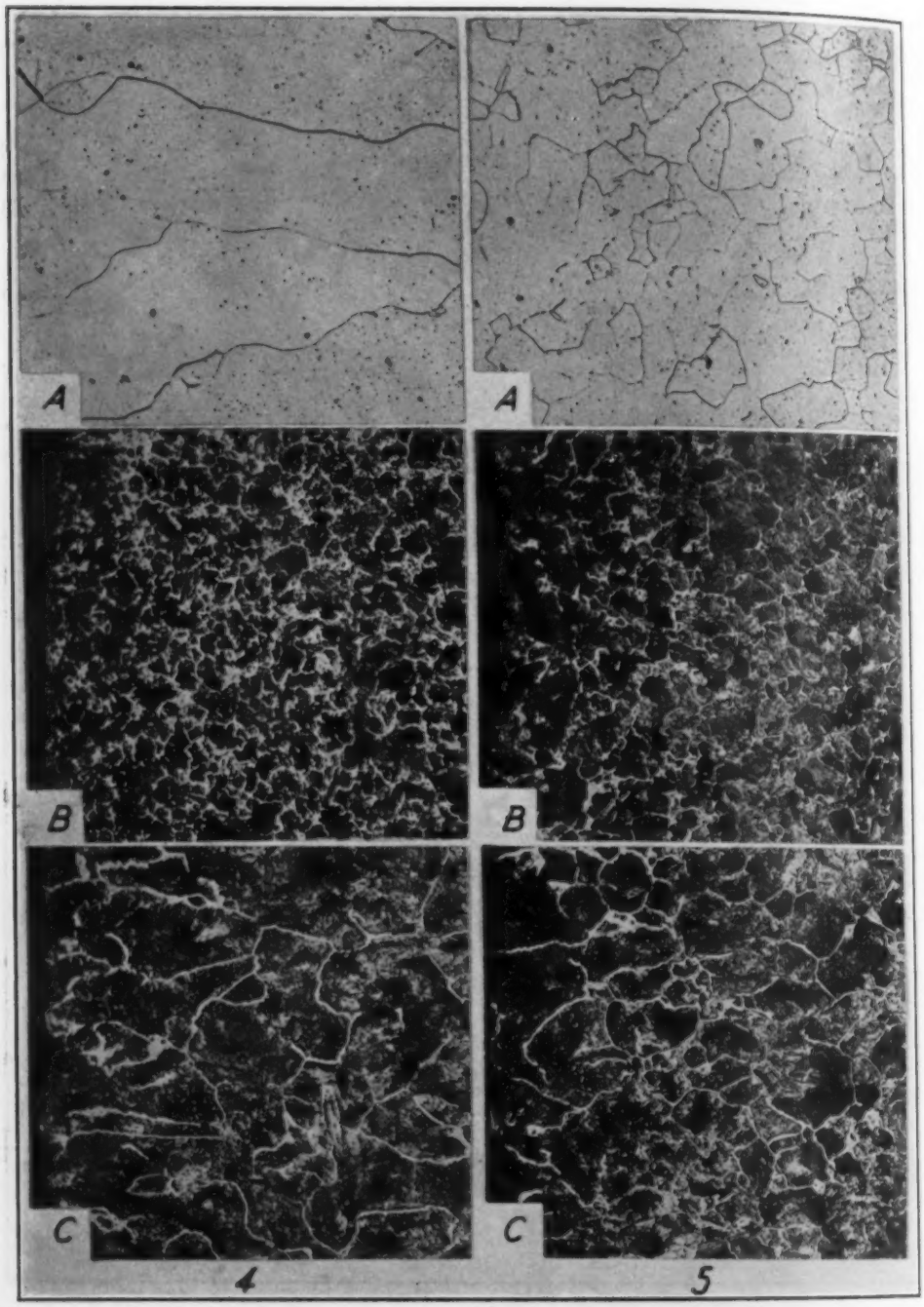
Fig. 1—Cross-section of Specimen of Abnormal Carburizing Steel Annealed in Hydrogen at 1525 degrees Fahr. (830 degrees Cent.) for 24 Hours; the Outer Coarsely Crystalline Zone was Decarburized. Etched with Aqueous Ammonium Persulphate. Magnification 3 x.

to the zones decarburized by the hydrogen. Fig. 1 of this discussion shows a cross-section of a specimen from a bar of abnormal carburizing steel, after being heated at 830 degrees Cent. for 24 hours in an atmosphere of hydrogen. The outer zone seemed to be completely decarburized. It is of interest to note the columnar crystal formation in the decarburized zone, similar to that in a casting. Apparently the crystals of ferrite originated at the surfaces and then grew perpendicularly to the surfaces inward, as decarburization proceeded.

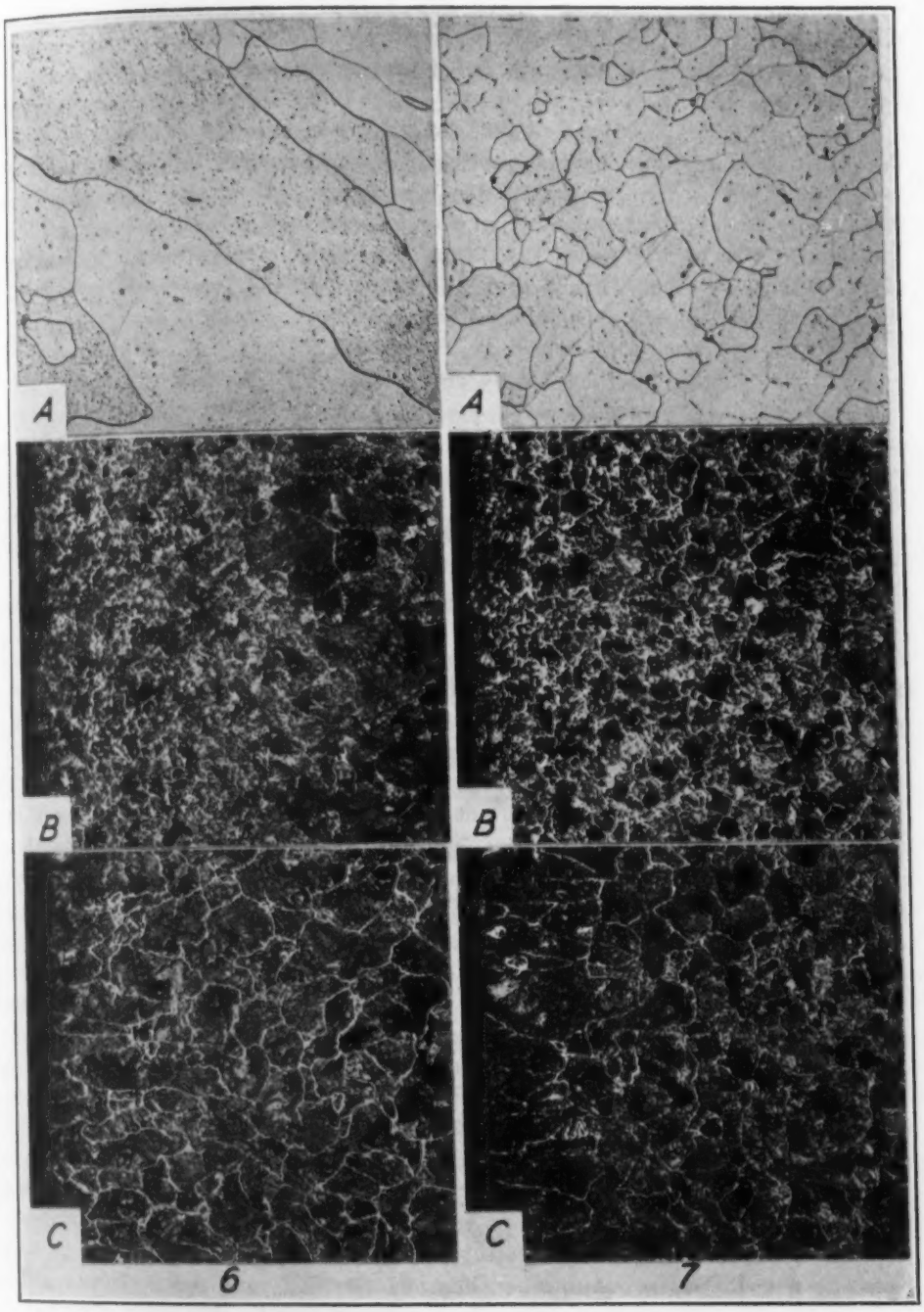
The specimens annealed in hydrogen were commercial steel of about 0.15 per cent carbon content treated with aluminum in the mold (4 pounds of aluminum to a 3-ton ingot) and had decidedly abnormal structures. Specimen No. 1 was an effervescent steel and had the most pronouncedly abnormal structure; specimen No. 2 was also an effervescent steel, and specimen No. 3 was a killed steel. One set of the three specimens was heated in hydrogen at 830 degrees Cent. for 24 hours, and another set at 940 degrees Cent. for 12 hours. The specimens were sectioned before



Figs. 2 and 3—Both of Specimen No. 1. Fig. 2 Annealed in Hydrogen at 1525 degrees Fahr. (830 degrees Cent.) for 24 Hours. Fig. 3 Annealed in Hydrogen at 1725 degrees Fahr. (940 degrees Cent.) for 12 Hours. Figs. 2a and 3a Outer Decarburized Zone After Hydrogen Annealing. Figs. 2b and 3b Annealed then Carburized—Carburized Layer of Interior not Decarburized by Hydrogen; Abnormal. Figs. 2c and 3c Annealed then Carburized—Carburized Layer at Surface Decarburized by Hydrogen; Less Abnormal. Etched with 5 per cent Picric Acid in Alcohol. Magnification 100 x.



Figs. 4 and 5—Both of Specimens No. 2. Fig. 4 Annealed in Hydrogen at 1525 degrees Fahr. (830 degrees Cent.) for 24 Hours. Fig. 5 Annealed in Hydrogen at 1725 degrees Fahr. (940 degrees Cent.) for 12 Hours. Figs. 4a and 5a Outer Decarburized Zone After Hydrogen Annealing. Figs. 4b and 5b Annealed then Carburized—Carburized Layer of Interior not Decarburized by Hydrogen; Abnormal. Figs. 4c and 5c Annealed then Carburized—Carburized Layer of Surface Decarburized by Hydrogen; Normal. Etched with 5 per cent Picric Acid in Alcohol. Magnification 100 x.



Figs. 6 and 7—Both of Specimens No. 3. Fig. 6 Annealed in Hydrogen at 1525 degrees Fahr. (830 degrees Cent.) for 24 Hours. Fig. 7 Annealed in Hydrogen at 1725 degrees Fahr. (940 degrees Cent.) for 12 Hours. Figs. 6a and 7a Outer Decarburized Zone After Hydrogen Annealing. Figs. 6b and 7b Annealed then Carburized—Carburized Layer of Interior not Decarburized by Hydrogen; Abnormal. Figs. 6c and 7c Annealed then Carburized—Carburized Layer of Surface Decarburized by Hydrogen; Normal. Etched with 5 per cent Picric Acid in Alcohol. Magnification 100 x.

carburizing (at 940 degrees Cent. for 8 hours) so that any change in normality in the interior of the specimen where decarburization by hydrogen had not occurred, as well as at the surface zone decarburized by hydrogen, would be revealed.

In Figs. 2 to 7, of this discussion, the micrographs at the top show the grain size of the decarburized surface zones after annealing at the lower and higher temperature; the micrographs beneath show the carburized layers after carburizing, at the interior and at the surface of the specimens. It can be seen that at the surfaces annealing in hydrogen, especially in specimens No. 2 and No. 3 (and at the lower temperatures) changed the structures from abnormal to normal.

The first presumption would be that the effect of hydrogen in changing an abnormal structure to normal, is due to the reduction by the hydrogen of oxides present in the steel. Other factors may also enter in, however. Hydrogen is not very active in reducing aluminum oxide, which was present in these specimens and which apparently was the main cause of their being abnormal. At the lower annealing temperature the size of the ferrite grains in the decarburized zone was much larger than at the higher temperature, and this may have been reflected in the larger grain size and thus more normal appearance of the carburized structure in the specimens annealed at the lower temperature. It will be noted that in the carburized layers the cementite envelopes were thicker in the effervescent steels than in the killed steels. This is usually so, and the fact that this difference persisted even after annealing in hydrogen, would indicate that any difference in oxygen content between killed and effervescent steel is not entirely eliminated by annealing in hydrogen.

The authors state they have not complete evidence for inserting the dotted lines in the diagram on page 987, and these lines do not seem to the writer to help clarify matters. In the carburized layer of a high oxygen steel the cementite coalesces and separates from the ferrite. This indicates to the authors that in such a steel cementite is less soluble in the austenite. Are we justified in indicating this on the equilibrium diagram when not a single point on the line has been determined accurately? The writer does not find in the paper any proof that iron oxide shifts the eutectoid point to 0.45 per cent carbon content, at which point the authors put one end of the line s′-e′.

Similarly, with the line s-e″ the authors do not present evidence that such an usual phenomenon as a decrease of solubility of cementite in austenite with increasing temperature really occurs in steels high in aluminum. Are we warranted in drawing lines on the equilibrium diagram on the sole basis of carburizing experiments? It would seem to be necessary actually to make up the alloys of the different compositions and then study the transformations and structures at the different temperatures. The authors put in the line s-e″ because they were unable in carburizing to get a hypereutectoid zone in steel melted in alundum crucibles. On the basis of the carburizing tests alone, therefore, the diagram of the carbon alloys above eutectoid composition of such steel, would be a blank.

Again, in regard to the discussion of the eutectoid phase described by Gat, the authors are apparently not ready to accept the existence of Gat's eutectoid phase, or the validity of his experimental procedure. Yet they make use of his observation about the hardness of the eutectoid phase, to support their theory as to the mechanism of formation of the ferrite surrounding coalesced cementite. Comstock[1] in his discussion of Gat's paper has indicated the uncertainty surrounding such scratch hardness tests. It would seem better to try to determine whether this ferrite is actually hard before accepting support for a theoretical point in such a doubtful premise.

Written Discussion: By Frederick Sillers, Jr., scientific aid, Bureau of Standards, Washington, D. C.

In that portion of the paper dealing with the X-ray analysis of normal and abnormal steels, it is noted that the specimens chosen as typical were ingot iron (Spec. 65) and S. A. E. 1020 steel (Spec. 77). These were in the form of filings reduced to 200-mesh in an agate mortar. No mention was made of annealing the particles subsequent to these operations.

It is believed by the writer that the difference in composition of the two specimens and also the fact that the material was not annealed after the powdering operations should not be disregarded in interpreting the X-ray data. It would also be desirable to know the accuracy of the fourth significant figure in the values given for the lattice parameters if importance is to be attached to differences in the last place.

Of the results obtained by the authors in the X-ray analysis of a weld it is stated, "The lines on the film are spread and some of the first lines were almost double lines. As a result the readings were erratic." Two different values of lattice parameter were deduced depending on what part of the line was used for measurement and it was suggested that the weld was made up of normal and abnormal steel. This suggestion appears to the writer to be rather a precarious one since the "spread" of bands may arise from distortion of the crystals on filing[2] and crushing them in a mortar.

Commercial normal and abnormal carburizing steels similar to each other in composition were examined by means of the X-ray at the Bureau of Standards. The specimens were of the type used by Dr. Lester of the Watertown Arsenal when it is desired to preserve the original structure of the material. The specimens were machined out in the form of strips, the upper portions of which were truncated prisms. The top surfaces of the prisms were polished and etched as for microscopic examination. The specimens were then screwed to a brass strip with their etched surfaces in alignment and the diffraction patterns (separated by the septum of the cassette) obtained side by side on the same film. A print of the film showing the first nine bands is given in Fig. 1 of this discussion.

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[1] G. F. Comstock, TRANSACTIONS, American Society for Steel Treating, Vol XII, 1927, p. 415.

[2] A Study of Crystal Structure and Its Applications (Part VI), W. P. Davey, *General Electric Review*, Vol. 28, p. 588 (1925).

The bands coincide exactly, even to the fourteenth band at the extreme edge in the original negative. Hence, no apparent difference in planar spacings exists and consequently there is no difference in lattice parameter. The K_a doublet of molybdenum is resolved in all bands except in the first one, thus showing freedom from lattice distortion. The more pronounced needle-like character of the diffraction spots in the normal steel indicates that this steel has a coarser grain size than the abnormal steel, and this fact, of course, confirms the results of microscopic examination.

Two specimens of electrolytic iron remelted in vacuo, one being high in oxygen and the other low, are being studied by the method described.

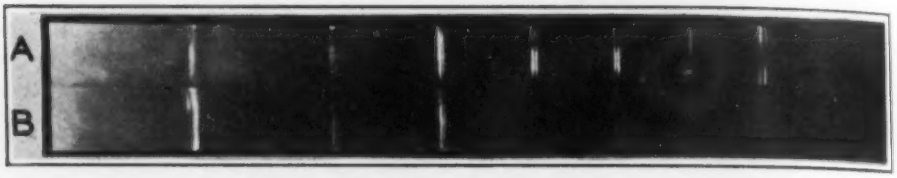

Fig. 1—X-ray Diffraction Patterns of Normal and Abnormal Commercial Carburizing Steels. A. Normal. B. Abnormal.

A preliminary film, developed before the required exposure period had elapsed for the purpose of this discussion, did not indicate a difference in planar spacings. Other films will be prepared, however.

Written Discussion: By John D. Gat, metallurgist, Pittsburgh.

The valuable work of these authors is practically the first, though most probably unintentional answer to my plea, many times expressed in print, to divorce the conception of crystallization and the accompanying phenomena grain growth from definite chemical and metallographic characteristics stipulating the behavior of steels in quenching. As long as cementite is lined (at the present it seems to be better to omit any attempts of positive definition of the nature of the substance constituting this layer) the steel will behave differently from properly deoxidized metal. Dr. Harder and his collaborators have mentioned no other indicator of abnormality and were able to reach concordant and promising results. It would be interesting to know whether in the course of this investigation any attention was paid to other metallographic features or were all conclusions reached on the basis of this particular index.

Allowing for the difficulty involved in the correct interpretation of reproduction photomicrographs as in Figs. 9 and 11 one might distinguish inclusions mentioned by the present writer at the Washington Sectional meeting in January, 1927. They appear even more pronounced than it was possible to develop on very low carbon steels. Were they actually observed or is their presence attributed to polishing defects? Both photomicrographs were taken from unoxidized, i. e. abnormal stock and should the fact of their presence be established one has here a further confirmation of the theory that the presence of oxygen in carburized iron leads to the formation of definite structural constituents.

One might take exception to Dr. Harder's opinion regarding the necessity for complete solution of oxides in austenite followed by the precipitation of oxygen-rich material on cooling. Experimental procedure of these series was much similar to the conditions under which Archer studied migration of carbon on annealing malleableized cast iron. If under the comparatively low temperatures used in both series, highly soluble carbon did not penetrate inside of the mass of crystals, one could expect that the mechanism of the reaction would be about the same in case of the less soluble oxides and instead of going into solution and then precipitating iron oxide, it would travel along grain boundaries. Under these conditions the film at the grain boundaries, supersaturated in regard to oxygen, would rather be independent from the whole mass of metal than to form a metastable component of it. One is strongly inclined to think that the latter can hold in solution quite considerable amounts of the gas. On numerous examinations of steels with widely different degrees of oxidation ranging up to one tenth of one per cent, the writer failed to find even the slightest traces of the mesh referred to in the paper.

There hardly can be any better proof of the oxygen theory of hardening troubles than melting under ideal conditions in an oxidizing atmosphere. This method is free from most of the objections to which all previous attempts to incorporate oxygen-bearing materials into metal under investigation were subjected. Its results are so convincing that definite conclusions from them become almost axiomatic and our present problem takes on the aspect of establishing the mechanism of hardening as affected by oxygen and the form in which the latter is found in steel, rather than finding its presence.

While the technique of these series hardly can be improved upon, some further study may be welcomed to make the conclusions drawn in the paper less open to criticism, principally in regard to the influence of the presence of alumina in contact with molten steel and the theory of the mechanism of formation of "abnormal" structure.

An experiment can be very illuminative where a sample of abnormal steel is melted in an alundum crucible under a neutral or oxidizing atmosphere. The peculiar behavior of steels subjected to the influence of aluminum oxide during the melting process, the difficulty of producing the hypereutectoid zone, together with the fact that the same steel kept from the contact with alumina when in molten state does not exhibit this property, strongly suggests that our present conception of irreducibility of alumina could probably be modified and the phenomenon explained in the light of the properties of the aluminum-iron system, one of which, carbon repellent quality, is well established already. Conversion of a sample of abnormal steel into the normal variety after melting in an alundum crucible would be an excellent demonstration of the correctness of this theory.

The proposed explanation of the formation of abnormal structure is based chiefly on the assumption of sluggish penetration of oxides in austenite. This point of view is supported by the results of heating low carbon steel under strongly oxidizing conditions and comparatively lengthy time periods, but at temperatures at which the metal is still solid.

The presence of oxide films proves only that the oxide penetration at the temperatures of experiments is low. It is difficult to advance any objection to the proposed theory of the formation of the white cementitic lining provided these oxygenated areas remain at the grain boundaries even after the addition of a considerable percentage of carbon. At the same time it is impossible to omit from consideration the fact that oxidation causing abnormal structure is independent from carburizing procedure and is affected by furnace practice only, when the metal is still liquid. One is inclined to disagree with the interpolation of the behavior of substances in solid state so as to cover the realm of liquids, especially when quite numerous observations repeatedly failed to substantiate the point of view that iron oxide does not freely alloy with iron to a certain extent.

Viewed from this standpoint one is at a loss to see the reasons for oxygen segregations at the boundaries of crystals and therefore to accept the theory of supercooling in regard to cementite and to explain hardening of the white boundaries originating around the cementitic mesh as due to a decrease of the crystalline dimensions of ferrite in preference to the conception of an insoluble iron-carbon-oxygen alloy in alpha iron. There is no doubt that smaller grain size expresses itself in higher hardness values, but variations, in the case of ferrite, would probably be inside of a considerably narrower range than actually observed on badly oxidized and carburized specimens.

Oral Discussion

H. W. McQuaid: I have read the paper by Prof. Harder and his associates and have noted the results. These agree with the published results to date and also with the many experiments made by the writer covering this particular field. It is gratifying to note that the original explanation as offered by Mr. Ehn and myself is strengthened by the evidence submitted, particularly the X-ray analyses, which indicate the presence of some foreign material in solid solution in the ferrite. Results such as these, while very difficult of exact definition or explanation, are a valuable addition to the data originally submitted.

It is difficult to explain why the alundum crucible should have any different effect than the magnesite crucible in melting the steels, and it is hoped that more work may be done to explain this particular point, since it may develop that the linings of furnaces and ladles may have some effect on the structure of the steel.

The check of electric welds was used at the Timken Roller Bearing Company in 1922 to discover whether or not a process could be developed whereby a welded ring could be substituted for a ring from seamless tubing. The carburizing test was used to check results and one of the conclusions was that the acetylene weld would not be satisfactory since the filled-in steel was very abnormal, whereas an electric weld, if properly made, can be used, since the abnormal, over-oxidized steel could be forced out into the flash and removed, leaving the weld itself normal in structure. The carburizing test is a very delicate check on the presence and character of a weld.

The theoretical discussion as to the mechanism of the formation of the abnormal structure observed in certain steels when carburized sounds plausible. The writer has made several checks as to the position of the critical points on abnormal and normal steels of the same carbon content and has been unable to find that there is any difference in any case. The martensite observed in the abnormal steel seems to be less stable and to require more rapid quenching.

Since the first evidence of the effect of variation in the steel being carburized on the results obtained in case hardening in 1920, there has been much discussion pro and con as to the causes, and in some cases, as to the existence of the difference in carburizing steels as first set forth by Mr. Ehn and myself in 1922.

When first presenting the paper covering this phase of case hardening, it was thought merely to point out an explanation of what was to the makers of case hardened, water-quenched parts, such as roller bearings, a very important problem. I have seen thousands and thousands of roller bearings which were soft, which we could not get through our hardening department, and since at that time we were running the bearings through by heats from the steel mill, we found that the scrap, the rejections and the final tests almost invariably went by heats. By following them back through the carburizing and the water quenching and the hardening, all the way back to the ingots, we found that we could separate them and we could eliminate them.

Of the papers which have been presented since then on normal and abnormal steel, little, if any, evidence has been submitted which does not support the theory advanced in the original paper that the difference was due to the presence of oxide products in the steel. So far as I am concerned, it was originally a theory and it still is a theory, but we find, and it is nearly true, that you can start with a heat of steel and check it from one end to the other, and after you add your deoxidizers, if the steel is made right and the deoxidizers are sufficient, you are going to get a normal structure.

There is no disputing the fact that very much expensive trouble, even with the best quenching equipment, would crop up in water quenching carburized pieces due to the presence of soft spots. It is also true that this difficulty can be commercially eliminated either by keeping the so-called abnormal steel out of the plant or by substituting a brine or caustic quench for the water. We still do that every day. We get lots of steels we cannot get hard in water, so we put them in caustic and get our results that way.

The terms "normal" and "abnormal," which were first used by the writer, were meant to correspond to "usual" and "unusual," i. e., a steel which would go through the case hardening operation without difficulty was termed "normal" steel, indicating that it would give the results usually expected,—and we expect to have them go through with 99.9 per cent, passed on the file test; and "abnormal" steel was meant to cover that class of steel which would not give the results desired. It does not necessarily imply that abnormal steel is abnormal in all respects but

simply as regards its quenching results. It is well known at this time that the fine-grained steel with a normal hypereutectoid zone is probably the most desirable steel for all purposes, since the large-grained, very normal steels are apt to be brittle after quenching.

One of the most noticeable things about that was that the carburized abnormal steel was tough and that the carburized very normal steel was brittle. We tried to get carburized steel that would harden satisfactorily and still be tough, and the way we get that is not by heating it in any particular gas or melting it and remelting it, but we do it by going back to the furnace, either electric or open-hearth, and treating the steel to give us the grain size. If you want steels of a certain grain size, you want them for some purpose, such as steering knuckles, pins, etc., you want steels that are tough, and to get them tough, you want a fine grain; and to get a fine grain, you add aluminum or vanadium in the ladle and you get it, depending on how much you add and the way you add it. But before you add it, you have to have a good, clean steel. You can change a coarse-grained normal into a fine-grained normal steel very easily, but you have to do it in the ladle and perhaps in the mold. The easiest place to do it is in the furnace if it is an electric furnace, or in the ladle if it is an open-hearth heat.

Much work has been done but little published on the advantages of the fine-grained normal steel and the manner in which it is produced, but at the present time this is a commercial product and very desirable for many purposes. The size of the grain after carburizing is a very valuable indicator of results which can be expected under shock loads as well as in the general heat treating operation.

F. G. SEFING: I would like to ask Dr. Harder whether the accuracy of the X-ray analysis is better than one-half of the one per cent?

In regard to the question of determining the causes of abnormality, we have done a little work at Michigan State College to see whether we could not make normal steels and abnormal steels after they were poured, and we did take various samples of normal and abnormal steels and make them abnormal and normal at will. To date we have not received any sample of abnormal steel which we have not made normal. In other words, we have made every sample of abnormal steel normal by heating to 2000 to 2025 degrees Fahr. and letting it cool, either slowly or by quenching. The resulting steel is in some cases ideally normal. Starting with abnormal steels, I have duplicated some tool steels that were submitted to me by manufacturers as ideally normal steels. Of course, nothing was done excepting to give it that heat treatment at 2000 degrees Fahr., and with the low carbon steels making the high carbon case with the standard McQuaid-Ehn carburizing treatment.

I merely mention this method of control as another mode of attack at this rather baffling problem of normal and abnormal steels.

O. E. HARDER: With regard to the papers by Mr. Epstein and Mr. Sillers of the Bureau of Standards, I prefer to reply to those in written discussion later.

With regard to the discussion by Mr. Gregg, our interpretation of the results obtained indicates that formation of massive cementite is due to a reaction which takes place above the eutectoid temperature and not to diffusion after the pearlite has been formed. It is difficult to see how it would be possible for the lamellar pearlite, having been formed, to diffuse in certain cases and not in others. The temperature below the eutectoid temperature is unfavorable to rapid diffusion of cementite. If Mr. Gregg would attempt to take well-formed lamellar pearlite and then cause it to diffuse into massive cementite particles of the size found in abnormal steel, he will find that it will take enormously longer time than that involved in the usual cooling of carburized steels as in the McQuaid-Ehn test.

His experiments with electrolytic iron involve two phenomena. First, if he carburized electrolytic iron as deposited, it is entirely possible that that iron contained a considerable amount of dissolved gases, or occluded gases, and we may reasonably expect that to affect carburizing. We found that, in most cases, abnormal steels when melted in vacuo showed gas liberation during cooling, and that these same steels showed more nearly a normal structure after having been melted in vacuo. In the case of the vacuum-melted electrolytic iron, the question of the contamination of the iron due to the container in which it was melted is very important. If he melted in magnesite crucibles, as did Yensen in his early work on electrolytic iron, then the molten iron was probably saturated with magnesium oxide at the melting temperature. This magnesium oxide, according to our results, would produce a type of abnormality in the steel. If he used alundum crucibles, the results would be similar.

In reference to his suggestion of quenching the steels from just below the eutectoid temperature, it appears to us that it is even more important to study the location of the Acm line, particularly in steels which contain a considerable amount of iron oxide, and we hope to give this phase of the investigation some attention at a later date.

In regard to Mr. Merten's discussion, it seems to me that the father of the paper should have the privilege of naming it, and that these godfathers should not object.

In regard to Mr. McQuaid's discussion, I think that there is a problem with reference to all containers, furnace liners, etc., and that there must be certain furnace linings which are not appreciably soluble in the molten steel and therefore do not add these oxides to the steel. Alundum we find is quite active in that regard; magnesite seems to be also active.

Authors' Closure

In regard to the discussion of our paper by Mr. Epstein, it was our intention to keep away from commercial processes of making steel as a means of trying to determine the cause and character of the abnormality in steel. The commercial process involves too many variables to be used as a starting point in the study of such problems.

Mr. Epstein is undoubtedly correct in that a high phosphorus content would produce an abnormal structure in steel, and the mechanism of formation of such structure would probably have to be accounted for in some such way as we have proposed.

In connection with Mr. Epstein's discussion of the oxygen content of abnormal steels, the question is immediately raised as to the reliability of the oxygen determinations. It is interesting to review Mr. Epstein's researches on abnormal steel annealed in hydrogen. The difference in grain size which he observes in the specimens annealed at two different temperatures, that is 830 and 940 degrees Cent., is undoubtedly due to the fact that his ferrite at the lower temperature was in the form of alpha iron while at the higher temperature it was in the form of gamma iron. This material on cooling would necessarily have to change from the gamma to alpha iron and this recrystallization would involve the formation of a new grain size and would appear to account for the fact that the smaller grain sizes were observed in those specimens which were annealed at the higher temperature. It is well known that alpha iron will show pronounced grain growth at such temperatures as 830 degrees Cent. This effect of having annealed one of the specimens in the gamma range and the other in the alpha range seems to have been overlooked by Mr. Epstein.

Mr. Epstein assumed that the abnormal structure in the original steel was due to the presence of aluminum oxide. The amount of aluminum added was very small and the character of the abnormal structure which he obtained does not indicate that this abnormal structure was due to alumina. Our specimens which were abnormal due to alumina would not produce a hypereutectoid structure and Mr. Epstein has produced hypereutectoid structure in his abnormal specimens. It would, therefore, be our opinion that this abnormal steel owes its abnormality primarily to iron oxide. It seems unfortunate that Mr. Epstein did not make oxygen determinations of the decarburized rim of the specimens treated and the core of the same specimens. It would seem more than likely that annealing steel in hydrogen would result in the removal of the oxide just as rapidly if not more rapidly than the removal of the carbon. Our interpretation of his results would then be that he deoxidized the rim of this steel and therefore changed it from an abnormal to a normal steel, and that the decarburization which he observed was simply a related phenomenon and had nothing to do with the normality of the steel. His observation with reference to the thickness of the cementite envelops is exactly what is to be expected and it appears that the abnormality in the core of the specimen which he tested persisted even after the annealing treatments used.

Mr. Epstein seems to have misunderstood the purpose of Fig. 36. It is not expected that the iron-carbon diagram, which is rather well established at the present time, should be modified as shown in our figure except in the discussion of abnormality of steels and that should not be accepted unless these lines have been located and their existence estab-

lished by sound experimental work. It will be observed that this diagram was marked a "diagram to illustrate the probable mechanism of the formation of the microstructure in abnormal steels." It appears to us that we have enough experimental information now to suggest that the mechanism is somewhat like that outlined in our paper. This applies to the lines s'-e' and s-e".

In regard to Gat's eutectoid phase, Mr. Gat seems to have used two methods of attack; first, that of etching, and second, hardness testing. It does not appear to us that his etching test indicates a microstructure other than what we have found in ferrite, and we have assumed that his hardness tests could be made with a considerable degree of accuracy and the mechanism which we have suggested would seem to account for the hardness which he has observed and reported. Perhaps these hardness tests should be further confirmed.

We have under way a continuation of this investigation in which it is expected that addional information will be obtained regarding the location of the Acm line under all varying conditions, which we have discussed.

Mr. Sillers' question with regard to the results which we have obtained by X-ray analysis requires first some further explanation as to our method of procedure. The samples for X-ray analysis were prepared by filing from the large pieces using a very fine file so that as filed practically all of the material would pass through 200-mesh silk bolting cloth. As a result the amount of grinding in the agate mortar required was very little. It is true, of course, that the material was in somewhat of a strained condition due to the filing operation. It seems quite unlikely that our results are in error because the films were read and calculated by two or three people with good agreement in the results obtained. The results consistently gave the values which we reported in the paper and indicated quite clearly the difference in parameter in the normal and abnormal steels. Since our samples were always compared with sodium chloride as a standard, it is not possible to reproduce the photographs of the films for demonstration. It appears that Mr. Sillers has used somewhat smaller cassettes than we used, and that would make it more difficult to observe a difference in the position of the lines of the normal and abnormal steel. It would appear that it would be better practice to compare the steel with a definite standard rather than to compare the two patterns on the same film. Mr. Sillers will probably get more dependable results in his research if he compares the different samples of steel with some standard such as calcite or sodium chloride, makes his readings, and then make his calculations independently rather than simply try to compare the lines in two samples exposed on the same film.

In reply to Mr. Sefing's discussion, Dr. Wheeler P. Davey may be quoted as authority for the statement that he considered unit parameters calculated from X-ray analysis to be accurate to $\pm$ .003 Angstrom units. This means an accuracy approximately 1/10 per cent rather than 1/2 per cent. In our own work we have found that with some experience the

results obtained by different persons will agree well within the limits quoted by Dr. Davey. The results reported by Mr. Sefing from his experiments on tool steels are rather surprising and apparently not in agreement with the results reported by others, but who were working on carburizing steels rather than tool steels. It will be a very interesting development if Mr. Sefing can show that his proposed treatment has general application.

One part of Mr. Gat's discussion touches on a point which apparently we did not make clear in our written publication. It has been our experience that the microscopic examination of abnormal steels generally reveals that sonims are present in or adjacent to the massive cementite. It seems natural to expect that sonims are rejected to the austenite grain boundaries and have a definite influence in controlling grain growth at elevated temperatures, and our experiments on the rate of diffusion of oxides in the steel at carburizing temperatures seem to prove that the austenite saturated with reference to the sonims would be adjacent to the sonims and the extent would depend upon the time of holding at the elevated temperature. Our conception of the influence of the sonim on the formation of cementite is that a sonim may function as a nucleus about which the cementite precipitates, or what is more probable, that the area adjacent to the sonim has a higher oxygen concentration and therefore is a region which first becomes supersaturated with reference to carbon or carbide. The concentration of these sonims at the grain boundaries, of course, would have a bearing on the appearance of the carbide at the grain boundaries rather than throughout the grain and apparently is the cause of the depletion of the austenite solid solution with reference to carbon and the resulting formation of ferrite adjacent to the massive cementite. In the case of hypereutectoid steels, particularly cast steels, it appears that sonims may have a somewhat analogous property in which they cause the formation of ferrite grains and make it difficult to heat treat the castings so as to get uniform distribution of the pearlite and ferrite areas. Mr. Gat's suggestions with reference to further desirable investigations on this problem of abnormal steels will be kept in mind in connection with our further researches on this subject.

INFLUENCE OF THE STRUCTURE "AS CAST" UPON MANUFACTURING AND QUALITIES OF SOME ALLOYED, ESPECIALLY HIGH STEED STEELS

By Dr. Ing. F. Rapatz

Abstract

This paper deals with a constituent of many steels known as ledeburite, this corresponds to the eutectic of pig iron. It is shown that there is great variation in grain size in different parts of an ingot due to different rates of solidification. It is difficult to forge a piece of steel of large section so as to break up large grains once they have formed during the solidification of the metal. The melting point of the eutectic corresponding to the ledeburite is only slightly altered with chromium (up to 14 per cent), whereas in high speed steels this point rises up to about 2370 degrees Fahr. (1300 degrees Cent.) Heat treatment below these temperatures does not change the size of the ledeburitic carbide. It then becomes a problem of using small ingots with fine grain size with less forging, or using larger ingots with larger grain size and a greater amount of forging.

THE present paper* is a continuation of the researches of Oberhoffer, Daeves and Rapatz.[1] These investigations show that with rising content of tungsten and chromium, the carbon content, both of the pearlite and of the eutectic (ledeburite), are considerably lowered. Iron-carbon alloys of more than 1.7 per cent carbon are in the metallographic sense "pig iron". They are characterized by a constituent freezing and melting at about 2065-2120 degrees Fahr. (1130-1160 degrees Cent.) and not subjected to a change in size below this temperature.

Figs. 1 and 2 show the influence of the solubility of carbon in chromium and tungsten steels. These figures evidence the diminution of the carbon solubility, or in other words, the carbon-combining force of chromium and tungsten is so strong that, with 12 per cent of

*This paper is not completely up-to-date because its publication was for certain reasons delayed.

[1]*Stahl und Eisen*, April 1924, p. 432.

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tungsten, steels containing more than 0.5 per cent carbon have the eutectic constituent called ledeburite. With 12 per cent of chromium, the corresponding carbon content is 0.7 per cent. Chromium and tungsten steels have thus, with relatively low carbon contents, a constituent corresponding with the ledeburite of pig iron. A large number of the steels in practical use belong to this group. All these steels can be manufactured and treated correctly

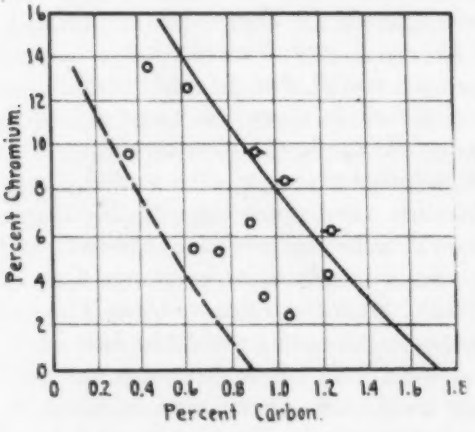

Fig. 1—Lines of Solubility of Carbon in Pearlite and Austenite in Chromium Steels.

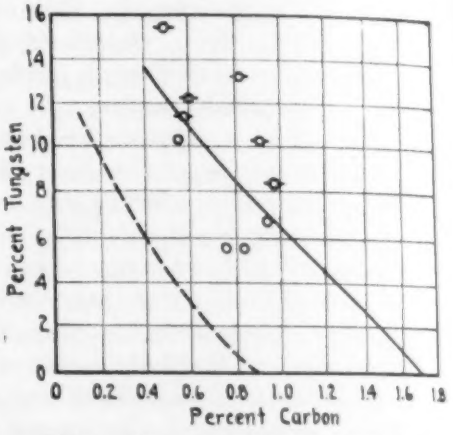

Fig. 2—Lines of Solubility of Carbon in Pearlite and Austenite in Tungsten Steels.

only when it is borne in mind that they, in the "as cast" state, contain a network which remains unchanged up to the melting point of the eutectic lying according to the chemical composition between 2100 and 2400 degrees Fahr. (1150 to 1315 degrees Cent.) and that this eutectic greatly influences the behavior at forging, annealing and quenching.

Four groups of ledeburitic steels are in practical use. They are as follows:

1. The most important are the high speed steels. They are used especially for high-grade lathe tools, cutters, drills and stamps, if such tools are required not to lose their hardness and cutting qualities up to temperatures of from 750 to 1110 degrees Fahr. (400 to 600 degrees Cent.). The chemical composition lies between 0.5 and 0.9 per cent carbon, 10 and 20 per cent tungsten, 3 and 6 per cent chromium. Even the steels on the lower limit belong to the ledeburitic steels, and increasing the elements increases the quantity of ledeburite also; molybdenum and vanadium act in a similar way to chromium and tungsten.

2. To the second group belong chromium steels, with 1.4 to

2.5 per cent carbon and 4 to 14 per cent chromium, used for cutting dies, punches, drawing plates, rings, gages and sometimes for cutters.

3. A third group is that of steels with 1.3 to 1.5 per cent carbon and 4 to 8 per cent tungsten. They are used for turning especially hard materials, such as chilled cast rolls, under moderate cutting speeds. More important than resistance to change of hardness by tempering is a high abrasive resistance, as the cutting edge is keeping a low temperature.

4. Finally, plain carbon steels with more than 1.7 per cent carbon also belong to ledeburitic steels. Considering their treatment and use, they cannot be called "pig iron"; like other steels they can be forged and hardened. In the experience of the writer, such steels are forgeable up to a carbon content of 2.8 per cent.

Now the principal consequences of chemical composition, manufacturing and treating of these steels are to be discussed, inasmuch as they concern the existence of ledeburite.

Casting

In a homogeneous steel, the network of ledeburite as a primary network cannot be eliminated by any usual heat; even the size of the network is normally nonchangeable. Now it is known and shown anew by Oberhoffer[2] that the size of the network, as with pig iron, is greatly influenced by the mode of freezing. When forged the network is only stretched, but never disappears, the consequences of a coarse network are to be still seen in bars elongated in a great degree.

The following experiments show the influence of the cooling rate upon the size of the network. A sample of steel containing 0.61 per cent carbon, 4.74 per cent chromium, 19.85 per cent tungsten, 0.83 per cent vanadium and 1.38 per cent molybdenum was taken just before tapping from the electric furnace and cast in cold water. Fig. 3 shows its microstructure.

A larger ingot undergoes in its different parts different cooling conditions. The parts near the surface are chilled by the walls of the ingot mold; the greater the distance from the surface the slower the steel is cooling. Therefore, the ingot has a fine network struc-

[2] *Stahl und Eisen*, 1922, p. 1240.

ture near the surface and a coarse one in the center. Figs. 3 and 6 demonstrate the difference in grain size between the center and border parts of the same ingot. In Table I the grain sizes of samples

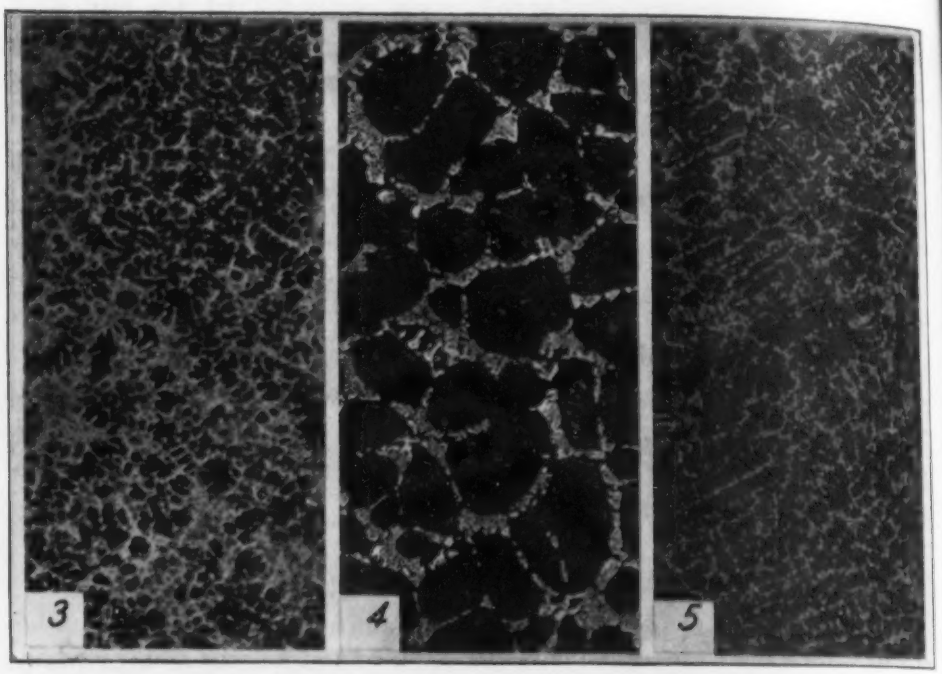

Fig. 3—Photomicrograph of High Speed Steel Quenched in Cold Water from the Molten State. Mag. 100 x. Fig. 4—Photomicrograph of the Network in the Center of an Ingot of High Speed Steel. Mag. 100 x. Fig. 5—Photomicrograph of the Network in an Ingot of High Speed Steel Near the Surface. Mag. 100 x.

Table I

Variation in Grain Size of Samples from the Same Ingot

Position of the Sample	Average number of grains per sq. mm.
Near the side surface of the ingot	2101
In the ingot axis just below the pipe	131
Center of the ingot	151
Ten millimeters from the bottom	726
38 millimeters from the side wall	186
Ingot edge on bottom	2600

of the same ingot are cited. The chemical analyses show that the composition in different parts differ only slightly. The carbon content lies between 0.87 and 0.95 per cent, chromium between 4.5 and 4.7 per cent, and tungsten between 19.5 and 20.2 per cent. There are thus only slight segregations, and the difference between the center and the surface consists only in the grain size of ledeburite.

It is to be seen:

1. The difference in grain size between the center and the surface is striking. The grain size in the ingot center is about 20 times larger than on the bottom of the ingot.

2. By quenching from the molten state the grain does not become finer than by the chilling influence of the ingot mold.

3. The chilling effect of the mold bottom is the same as that of the walls.

The following calculation intends to determine, whether circumstances in the practical manufacturing are such as to enable the ingot molds to absorb rapidly the heat which the steel loses up to the point of complete freezing of the steel. The calculation is based on a practical case where the ingot weighed about 200 pounds and the ingot mold has about the same weight. Before entering into the calculation, the following values must be found by experiments:

1. The total heat which the steel loses from the pouring temperature until cooled to air temperature. It has been found by the calorimetric method of quenching the molten steel in cold water.

2. The average specific heat of high speed steels was determined from 85 to 2100 degrees Fahr. (30 to 1150 degrees Cent.) as formerly.

3. The highest temperature of the ingot mold. The change of the temperature of the mold is represented in Fig. 6 and was in

Table II

Result of the Calorimetric Experiments

No.	Highest Temp. of Ingot Mold	Heat Which 1 Kilogram Loses From Pouring to Air Temp.	Heat Which 1 Kilogram Loses From Pouring to 1150° C.	Heat Which Mold Absorbs Rapidly From 1 Kilogram Steel	Tungsten Content
1	610	292 cal.	128 cal.	102 cal.	8.7%
2	610	285 cal.	132 cal.	96 cal.	13.9
3	600	253 cal.	103 cal.	93 cal.	18.46
4	600	254 cal.	105 cal.	92 cal.	18.40

all cases the same. It can be seen at once that the highest temperature is soon reached while the cooling proceeds slowly.

Four heats of high speed steel have been investigated in this manner and Table II shows the result of these experiments.

To make the freezing quick, the heats in column 4, that is to

say, the heats absorbed rapidly by the mold, ought to be greater than those in column 3, containing the heat the steel emits until the primary network is fixed [presumably about 2100 degrees Fahr. (1150 degrees Cent.)]. This, however, is not the case. The final grain size in the ingot center was formed during the second period, when the mold was cooling slowly, and the consequence of it is a coarse network in the center. But the foregoing calculation is to be restricted; it prevails only if the steel could freeze through the

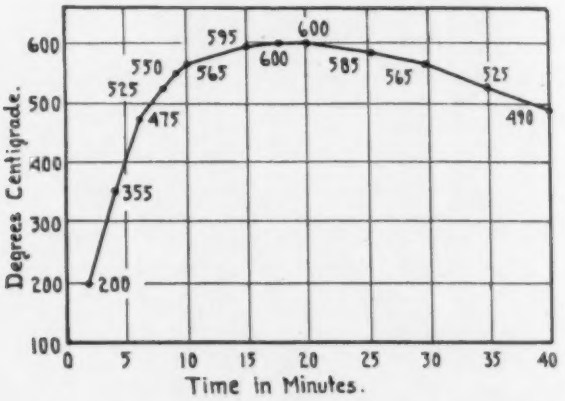

Fig. 6—Curve Showing Temperature of Ingot Mold and Time Elapsed After Pouring.

whole section at the same time. In reality circumstances for the formation of a fine network are even more unfavorable. The outer parts are favored by better cooling conditions than those corresponding to the calculation above, i. e., they are frozen when the mold is still able to absorb heat rapidly. This condition, favorable for the outer parts, prejudices the center, as the heat which the outer parts lose rapidly after freezing, is uselessly absorbed by the mold, to the disadvantage of the center.

With ingots tapering upwards, there is no hope to better it by thicker molds, because shortly after pouring the ingot separates from the mold. With ingots tapering downwards, in a short time a small air space will also be formed between ingot and mold, and besides the outer parts will, after reaching the temperature of the mold, act together with the latter as one thick, warm mold, and there is little hope for a considerable improvement by using thicker molds.

It results therefore that it is practically impossible to make the interior of larger ingots freeze quickly. In order to promote a

fine network through the whole section, very small ingots ought to be cast which, on the other hand, would have the fault of being brittle because of columnar crystallization. But the fact that tools sometimes are cast proves that the idea of obtaining a finer microstructure by casting small pieces instead of forging ingots, has been practically performed.

Forging

The forging of plain carbon or moderately alloyed steels up to 1 per cent carbon or more is done while the steel is still in solid solution. With ledeburitic steels this is not possible. Below the melting point of ledeburite, the ledeburitic carbides represent hard grains, behaving on forging like inclusions and being able to be distributed only by working the steels. Above the melting point forging is not advisable, because the molten part is likely to cause breaking.

Oberhoffer[3] demonstrated that the consequences of coarse network in the cast condition is felt in the forged piece. If the carbide network in the ingot is fine enough, or if the ingots are worked to a great extent, then an equal carbide distribution in the cross section is to be seen. In the case of large sized bars, for the manufacturing of which large ingots, with necessarily coarse network are needed, an equal distribution in the steel bar is not attainable. The following examples show the influence of forging upon the network in different cases.

1. A cast cylindrical piece of 50 millimeters diameter containing 12.5 per cent chromium, 2.10 per cent carbon, having a microstructure shown in Fig. 7 was worked by forging to a length four times the original. The microstructure of this piece is seen in Fig. 8. In this case the working was sufficient to distribute the carbides equally, as seen in cross section.

2. A round ingot of high speed steel of 300 millimeters diameter was rolled to a bar of 20 millimeters diameter, corresponding to a stretching out 250 times the original length. In the cross section the carbide distribution was equal, but in the longitudinal section, even if stretched 250 times, carbide lines are to be noticed. This experiment shows in a striking manner that the ledeburitic carbides behave in forging like inclusions.

3. A round ingot of 350 millimeters diameter containing 12.8 per cent chromium and 2.2 per cent carbon was forged to a bar of

[3]See foot note 2.

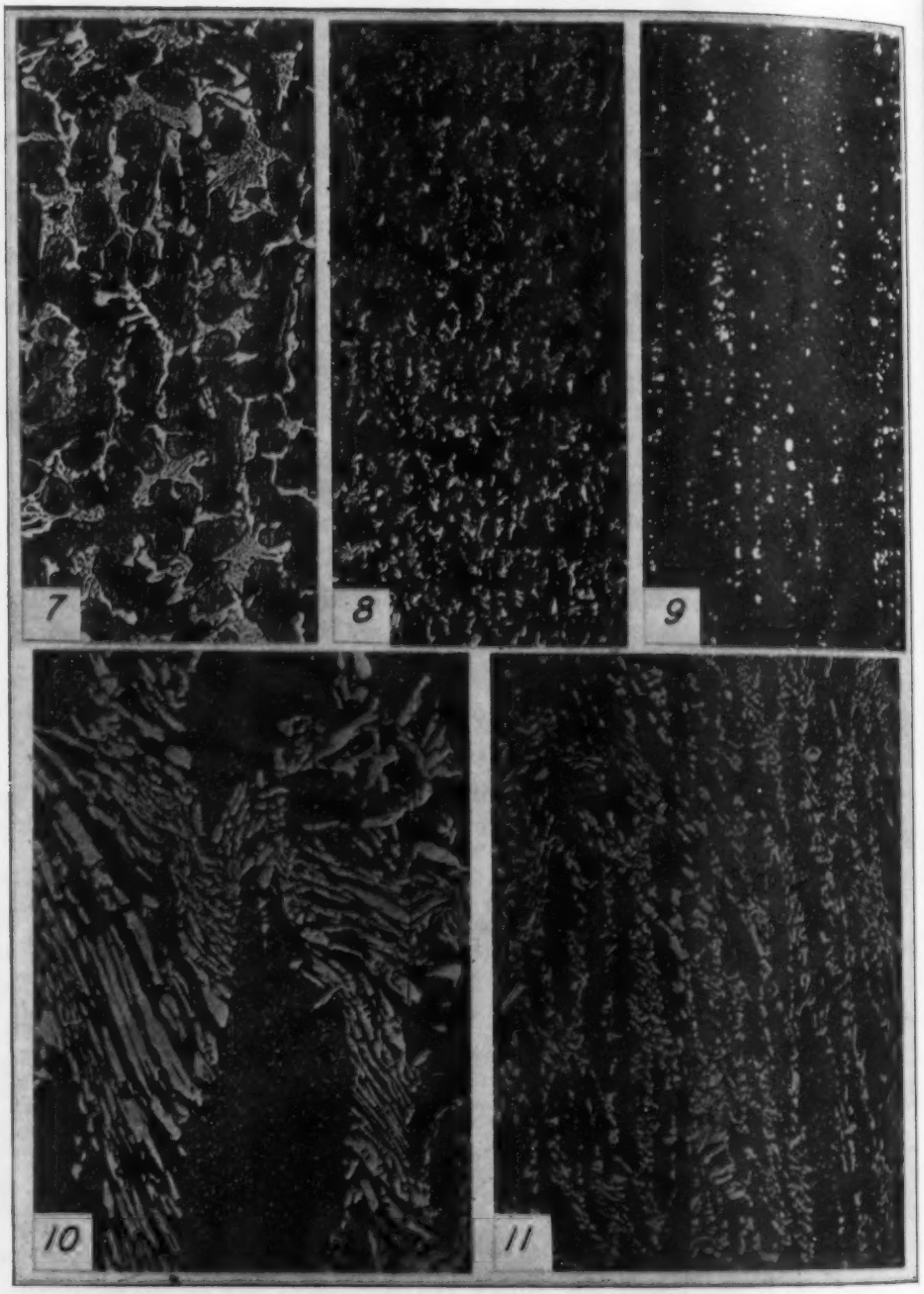

Fig. 7—Photomicrograph of the Network in a Steel Cylinder 50 Millimeters in Diameter, Cast in Runner Bricks. Mag. 100 x. Fig. 8—Photomicrograph of a Cross Section of the Same Steel as Fig. 7, but After Forging to Four Times the Original Length. Fig. 9—Photomicrograph of High Speed Steel after Elongating to 250 Times the Original Length, Carbide Lines are Still Seen. Mag. 100 x. Fig. 10—Photomicrograph of the Interior of a Bar of High Chromium Steel. Mag. 100 x. Fig. 11—Photomicrograph of the Outer Part of a Bar of High Chromium Steel. Mag. 100 x.

140 millimeters diameter. Thus stretched to 6 times the original length, pieces of the bar from the interior and the outer part were microscopically examined.

Fig. 10 gives the impression of a slightly changed cast structure, in spite of the considerable stretching. One sees that in this and similar cases, it is nearly impossible to have the carbide distribution, which would be the best one for the tool. The interior of the ingot during forging is only stretched, and the carbide-distributing kneading action does not penetrate into the interior. Besides, this kneading action the outer parts are in a more favorable condition, because they already have a finer network from casting. A kneading throughout of the interior could be accomplished only by an upsetting, followed by stretching, a procedure that, for practical reasons, is difficult to carry out.

The only possibility is to make the fault as little felt as possible and to choose between the two difficulties. If small ingots with a finer network are cast, stretching by forging must naturally be less. If on the contrary, ingots are large, in order to be able to stretch them more, the network gets coarse, as a consequence of the slow cooling rate.

It is of importance to decide whether it is better to cast large ingots and to stretch them correspondingly, or to cast small ingots and to forge them less. Experience seems to confirm that a better carbide distribution is obtained in the latter case. This has, furthermore, the great advantage of saving a great deal of forging or rolling work. It may be mentioned that large pieces of ledeburitic steels in their interior often show fiber, the cause of it is, in addition to elongated segregations of phosphorus or slag inclusions, mostly a course primary ledeburitic network.

As the network of ledeburite on forging changes neither by being dissolved nor by recrystallization, the stretching is a good test of how much forging work has been done. It can be found by reasoning as follows: Imagine an ingot or cube, each side of which is called a. Now, if the ingot is stretched by forging or rolling, the cube is worked into a prism, whose breadth and height may be called b and whose length is l. The working done by forging is expressed by the ratio $\frac{a^2}{b^2}$ as the volume of the cube is equal to that

of the prism, $a^3 = lb^2$, there ensues $a^2 = \sqrt[3]{l^2b^4}$ and $\frac{a^2}{b^2} = \sqrt[3]{\frac{l^2b^4}{l^6}} = \sqrt{\frac{l^2}{b^2}}$. The desired value $\frac{a^2}{b^2}$ is thus to be calculated by the ratio length to breadth of the stretched ledeburite grains. The usefulness of this method may be proven by the following practical case. An ingot with some 220 millimeters diameter was forged to a bar of 150 millimeters diameter corresponding to a stretching of 3.4 times the original length. When calculated by the described formula a figure of 3.8 was obtained. This conformity was for practical purposes good enough. For practical purposes it suffices to measure the proportion of width to length of a sufficient number of the stretched grains. However, if the stretching has gone so far that only parallel carbide lines are to be seen, the method is no longer applicable. This may be the case with a stretching of ten times. It may be said that this method holds good only if the ingot and bar have similar sections.

Annealing

All annealing experiments proved that in ledeburitic steels near the melting point of the eutectic, the network of the eutectic did not change. The changes referred only to the ground mass, which, according to the annealing temperature and the cooling rate separated more or less cementite. If forged steels with stretched carbide lines are annealed, these lines remain unchanged up to the melting point of the eutectic; only above that temperature do they change. The following experiment is instructive: a forged round bar of high speed steel (14 per cent tungsten) was drilled in the center; in the hole there was introduced a pyrometer and the bar heated an hour in such a manner that one end was heated to 2400 degrees Fahr. (1315 degrees Cent.), whereas the other end projected into the cold air. The microscopical examination along the bar showed a new network, at about 2280 degrees Fahr. (1250 degrees Cent.). At about 2300 degrees Fahr. (1260 degrees Cent.), all the carbides had been transformed into a new eutectic. With steels having more than 16 per cent tungsten, the melting point of the eutectic rises to 2370 degrees Fahr. (1300 degrees Cent.), whereas chromium up to 14 per cent is not able to rise to a point above 2100 degrees Fahr.

Quenching

When quenching ledeburitic steels, it must be borne in mind, that the ledeburitic carbides do not change until a quenching temperature corresponding to the melting point of the eutectic is reached. Above the melting point of ledeburite, new eutectic can

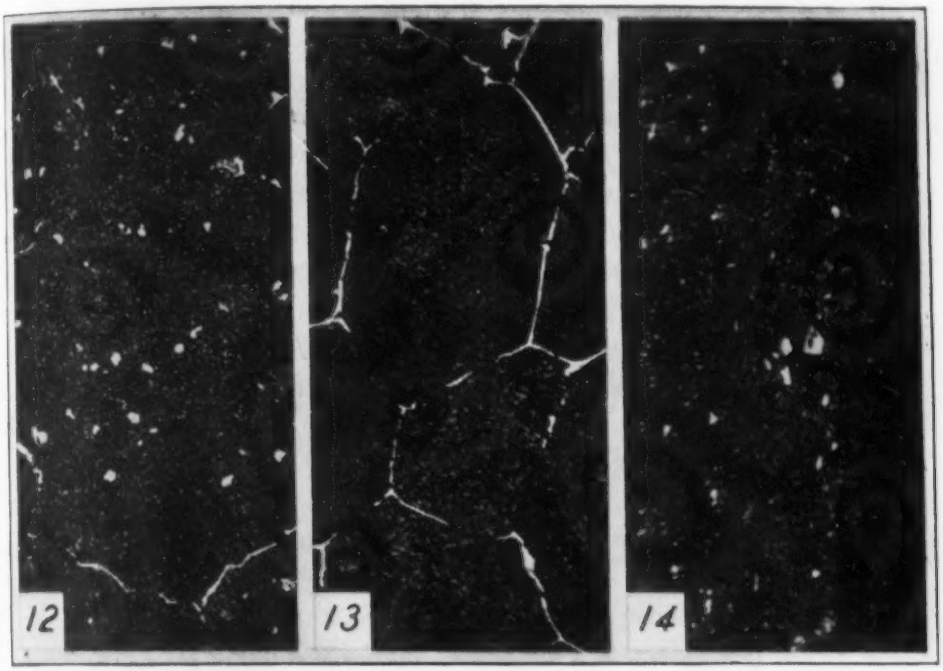

Fig. 12—Photomicrograph of Forged High Speed Steel Heated for 1 Hour at 2250 degrees Fahr. Mag. 100 x. Fig. 13—Photomicrograph of Forged High Speed Steel Heated for 1 Hour Above 2300 degrees Fahr. Mag. 100 x. Fig. 14—Photomicrograph of the Cutting Edge of a High Speed Steel Lathe Tool. Mag. 100 x.

be formed. But if the steel has been only for a short time at such a temperature, the carbides still remain unchanged, what happens if the steel is quickly heated and quenched without keeping it at temperature. As practical experience shows, high speed steel demands a high quenching temperature, as by this the cutting efficiency gets better.* High speed steels quenched from high temperature keep their hardness at tempering longer than those quenched at lower temperatures. The quenching temperature lies between 2200 and 2430 degrees Fahr. (1205 and 1335 degrees Cent.), thus in practical hardening the melting point of ledeburite is likely to be exceeded.

*Since this paper was written this has been clearly proven by some detailed papers by French, Strauss, TRANSACTIONS, American Society for Steel Treating, and by Rapatz, *Stahl und Eisen*.

For this reason, the high speed steels should be kept only for a very short time at quenching temperature so that the ledeburite carbides are not able to fuse together and form a new cast structure, as this produces brittleness and coarse fracture in the quenched steel. In modern salt baths where the hardening temperature is more easily checked a short soaking is not only allowed, but is even recommended to promote solution of secondary carbides. Increasing the alloying metals, tungsten, molybdenum, vanadium to a certain degree makes the steel less sensitive to overheating, that means that the diffusion of the carbides in a eutectic is delayed. At a certain quantity of alloying metals the steels become again more sensitive in quenching, probably because the great quantity of ledeburitic constituents makes the formation of new eutectic easier. A high carbon content favors overheating.

An important consequence of changing the iron-carbon diagram is the inability of being hardened in the presence of too great a quantity of alloying metals. In plain carbon steels up to 1.7 per cent carbon, martensite formed by quenching the solid solution, contains all of the carbon. By adding chromium and tungsten, the ability of dissolving carbon in austenite decreases and therefore also the maximum carbon content of martensite is reduced. It might be supposed that with high quenched high speed steels, the martensite contains no more than about 0.3 per cent carbon, the rest of carbon is in the ledeburite carbides. By adding chromium and tungsten, a point is reached where the groundmass has so little carbon, that it cannot be hardened by quenching.*

Table III shows the results of the hardness tests of such iron alloys. It is noted, as expected, that by overloading with alloying metals the steel loses its ability to be hardened, and it is shown that the limit at which the ability is lost, is higher with chromium alloys than with tungsten alloys. For example an iron-tungsten alloy that cannot be hardened, even regains to a certain degree that ability by adding chromium. The explanation is perhaps that chromium austenite requires less carbon to be hardened, or it may be that at a certain tungsten content by adding chromium, too, the latter selectively passes to the ground mass.

The chief reason for the cutting efficiency of the high speed

*More recent investigations by Bain and Grossmann, TRANSACTIONS, American Society for Steel Treating, make it probable that besides the carbon-combining force of tungsten and chromium, the suppression of the gamma region must be considered.

steels lies in the red hardness of its martensite. But the latter explains nothing about the rôle of the carbides imbedded in the martensite ground mass. Honda and Murakami[4] suppose that the hard carbide globules act in a similar way to saw teeth. To examine this theory, there was prepared a cross-section of a well worked, quenched and ground high speed lathe tool which showed four or

Table III
Results of Hardness Tests on Various Iron Alloys

	Composition						As Forged		Hardness if Quenched at 950°C		Hardness if Quenched at 1100°C	
	C %	Cr %	W %	Mo %	V %	Co %	Shore	Brinell	Shore	Brinell	Shore	Brinell
1	0.91	0.19	23.07	—	—	—	45	360	45	352	—	—
2	1.26	—	24.87	—	—	—	44	293	44	315	47	321
3	1.51	6.97	16.92	—	—	—	60	477	74	534	—	—
4	1.76	9.42	19.60	—	—	—	58	435	57	420	56	440
5	1.84	6.62	17.81	—	—	—	53	314	70	584	—	—
6	2.40	20.4	14.47	—	—	—	52	344	56	381	—	—
7	2.88	15.27	12.46	—	—	—	59	514	66	540	56	450
8	3.05	26.67	8.95	—	—	—	56	534	57	480	57	495
9	0.65	5.20	24.72	1.97	1.0	2.29	35	270	—	—	34	270
10	0.62	4.31	19.53	2.37	2.2	—	38	321	—	—	36	285
11	Ferrochromium 2.80% C. 60.0% Cr.....						60	450	—	—	60	450

five carbide globules along the cutting edge in a distance of one millimeter. The same tool was then used on a lathe until the cutting edge was dulled. But the microstructure did not show any change; it might perhaps be assumed that the distribution of the carbides had been altered or single globules had been broken out, but this was not the case.

If it proves to be true, that the carbide globules act like hard saw teeth set in a more tenacious ground mass, theoretical, mechanical speculations could perhaps throw light upon the most favorable distribution and size of the carbide globules. According to practical experiences, carbides of the same size and equal distribution seem to be the best. This is shown, too, by the fact, that larger high speed steel tools, where a regular carbide distribution cannot be attained, the performance is always less than with small tools. Beside, tools break easier in quenching, if they have a large

[4] *Journal*, Iron and Steel Institute, Vol. 101, 1920, pp. 647-57.

carbide network, especially with larger tools such as milling cutters.

It is in the same degree astonishing that the ledeburitic qualities of many steels, especially of the important high speed steels has remained unnoticed, though Fettweis,[5] clearly pointed to it 16 years ago. The most curious news about the origin and the qualities of the carbide network is often to be found, which some try to make disappear by annealing and others by forging. The proposal may be made, that steels of this kind should not be called double carbide steels but ledeburitic steels as by "double carbides" not only the ledeburitic carbides are understood, but many other more or less theoretically founded chemical compounds often present even in steel where no free carbide globules are to be seen.

Conclusions

1. It is pointed out that a great many steels, especially high speed and high alloy chromium steels used, contain a constituent corresponding to the eutectic of pig iron, and that these steels metallographically are pig iron.

2. Continuing Oberhoffer's research, the influence of various freezing conditions in practical manufacturing is treated. It is shown that the size of the network in different parts of ingots cast in iron molds differs greatly. It is stated that under practical conditions the interior of the ingot cools too slowly to allow the formation of fine network.

3. Several examples of the influence of forging are examined and correlated with the difficulty of obtaining regular distribution of carbides in large cross sections. A procedure is given for calculating from the stretching of the network the degree of elongation by forging or rolling.

4. The melting point of the eutectic corresponding to the ledeburite is only slightly altered with chromium up to 14 per cent, whereas in high speed steels this point rises to about 2370 degrees Fahr. (1300 degrees Cent.) Heat treatment below these temperatures does not change the size of the ledeburitic carbides.

5. The behavior of the carbides in hardening high speed steels at high quenching temperature is investigated.

6. The manner of action of the ledeburitic carbides when used for metal cutting tools is discussed.

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[5] *Stahl und Eisen*, 1912, p. 1866.

THE METALLURGICAL ASPECTS OF CAST IRON

By P. W. Blackwood

Abstract

The author of this paper points out how cast iron has not generally been regarded with great favor because of its low physical properties and heterogeneity and how the low price has had a tendency to handicap development of the cast irons of higher quality.

It is stated that cast iron is generally regarded as a simple alloy of iron and carbon, but that it is really not so simple, but rather a complex material consisting of free bodies, compounds and mixtures of compounds. Various factors which influence the properties are discussed.

The work of various investigators on the effect of additions of various elements to cast iron is discussed at some length, also some recent methods for the production of cast irons having an entirely pearlitic structure.

METALLURGICALLY, cast iron is the most complex material in ordinary use. It has never been regarded with great favor by engineers, as it has suffered from the assumption that the product of a shaft furnace must necessitate incalculable variations. The chief drawbacks to the use of cast iron, from the engineer's point of view, are: first, low physical properties, such as tensile strength, and more particularly elongation; second, lack of homogeneity, due to variations in the raw materials and in the conditions of melting and cooling. This heterogeneity is undoubtedly the cause of the engineer's distrust, as the designer can overcome difficulties that are merely due to low physical properties if these are reasonably uniform.

The cardinal advantage of cast iron, namely, its cheapness, has indeed in some respects been a handicap to its further development, for the price of the cheapest irons has tended to set a standard by which the price of high quality engineering castings may be judged. Indeed, the commonest objection among founders to the improvement of cast iron is that engineers will not pay for the improved

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results, a view which can scarcely be maintained for long. Nevertheless, many of the difficulties of introducing high quality irons for engineering purposes are due to the inadequate distinction made between cheap castings and those highly specialized engineering castings, the founding of which involves a considerable degree of technical control, careful selection of raw material, and considerable experimental work.

It is quite common for cast iron to be regarded primarily as a simple alloy of iron and carbon, contaminated with certain other elements, and investigation has been mainly directed to ascertaining the effect of these elements, which are often regarded as impurities, in modifying the properties of the basal iron-carbon alloy. Cast iron, however, is by no means a simple material whose properties are varied merely by the presence of impurities. It is a conglomerate not of simple alloys or solutions, but of free bodies, compounds, and mixtures of compounds whose composition or constitution is not always the same; and, further, the composition of the mixture is largely a function of temperature, and may show very great changes between the time of pouring into the mold and the attainment of atmospheric temperature.

Within very wide limits the character of a casting, particularly its solidity, freedom from defects, and general appearance, is influenced in a minor degree by ultimate composition. The mode of existence and the manner in which the components are distributed has a greater influence upon the properties than the actual quantities of the elements present. This is due to two principal causes. 1. A substance may separate and have an independent existence, and the effect produced will depend upon when the separation occurs, that is, before, during, or after solidification. If separation is effected before solidification, the substance has freedom to take a position in accordance with the relative specific gravity if during solidification freedom is restricted, there is no chance of complete elimination, and it will become entangled in meshes of the solidifying mass, or migrate in the direction of the still liquid portion. A substance which separates after complete solidification remains intimately associated with the mass; its ultimate distribution depends on the degree of liberty of the particles, and the degree of independent existence it attains will be to a large extent governed by its diffusibility. 2. The substance

may remain in solution, and thus have a direct action on the metal, and so modify its properties, that is, its tenacity, hardness, et cetera. It may also alter the behavior of the other constituents present.

It is well understood that the wide variation in behavior and properties of cast iron is not sufficiently explained by an ordinary chemical analysis, and the reason is that an ultimate analysis is simply a statement of the proportions of the elements which it contains, and as such does not indicate how they exist in combination or solution or suspension.

Structure of Cast Iron

Attention has already been directed to the importance of the constitution and structure of cast iron, and the prime factors in determining what this will be are, chemical composition, melting temperature, casting temperature, and the cooling velocity. The melting temperature, in conjunction with the presence of foreign elements, determines the constitution in the liquid condition. A substance cannot be considered apart from its effect upon others, and this applies, not only to the iron, but also to the other constituents. In general, the presence of a substance in solution depresses the freezing point of the liquid, and gives rise to a progressive solidification.

In the case of a complex body like cast iron a great many changes take place between the beginning of freezing and cooling to atmospheric temperature, and the sequence and nature of them depends upon the rate of cooling. If it be too rapid, some constituents are denied the time necessary for their separation, so that a certain amount of overlapping occurs. In a single casting of intricate design different portions cool at different rates, and in consequence the constitution and structure vary in different parts. A casting of unequal or complicated form may exhibit totally different physical and mechanical properties in adjacent portions. The unequal cooling also sets up internal strains, often of considerable magnitude, which reduce the strength of the material.

Structurally, cast irons are conglomerates of essentially two very different parts, one free carbon or graphite, which is embedded in the second, the latter a metallic matrix very much like the structure of certain steels. In fact, the main difference between various cast irons is the degree of weakening of the matrix by graphite. As

the graphite increases in quantity or spreads into large flakes the weakening increases. A further difference between cast irons is the carbon content of the matrix. It might be anticipated that the greatest strength would be obtained when the matrix contained about 0.90 per cent carbon, from the fact that the maximum strength of steel is obtained when the carbon is present to that amount, but it is found in actual practice that a smaller percentage of combined carbon gives the greatest strength. The reason is that with the higher carbon the cementite plates of the eutectic are so thick that if any one of them breaks it is likely to start a crack. A casting of complicated shape or unequal section varies greatly in the matrix, and consequently a lower average combined carbon content of, say, 0.6 or 0.7 per cent gives a stronger metal by the gain in strength due to the formation of smaller and finer pearlite, outweighing the loss that might be expected from making the matrix of lower carbon content.

Effect of Various Elements

Silicon ranks next to carbon in importance, not so much because of its direct action, but because of its influence on the solubility and stability of the cementite. The stability decreases and the graphite increases with increasing silicon. The results of experiments by Andrew seem to suggest that the stability of carbide is reduced by silicon even at quite low temperatures. It is practically certain that during the solidification of iron-carbon alloys, the carbide first separates, and is then decomposed with the formation of graphite.

Stead and Andrew have both arrived at the same conclusion, namely, that in some irons which become gray on cooling two independent cementites crystallize out, one a silico-carbide of iron, and the other a carbide of iron. The former separates first, and as all silico-carbides are very unstable, they are the first to dissociate into silico-austenite and graphite. In irons which contain only very small proportions of phosphorus two different cementites form and crystallize together as an eutectic mixture. It is to be regretted that so far no method is known by which the two cementites can be isolated and their composition determined. If such were possible, it would doubtless shed considerable light upon the affect of graphitization on the properties of cast iron. The notable grayness

of commercial irons containing silicon is due to the ease with which these carbides decompose by the action of iron silicide.

The carbide of iron itself is not quite stable. Stead has shown that pure white iron containing no silicon will, on heating, contain some graphite, the amount of which may be increased by heating the iron in contact with silicide of iron. The influence of silicon on iron carbide has been very fully investigated by Charpy, Grenet, and Hatfield, and as a result of an extensive series of experiments with irons containing sulphur and manganese, from which the carbides were separated and examined, the following conclusions were reached:

1. The silicon is not uniformly distributed, the carbide containing less silicon than the matrix, but that amount bears some relationship to the total percentage.
2. Manganese is in combination with the carbide to the exclusion of silicon.
3. Irons containing very much sulphur give carbide with low silicon, but no sulphur is found in the carbide, its action being obscure.
4. In slowly cooled irons practically the whole of the silicon is found in the carbide, and in quickly cooled samples any silicon not in the carbide is found in the solution.
5. In very open gray siliceous irons there is nearly always silicon in the graphite.

The action of silicon is to reduce the solvent power of iron for carbon, so that the eutectic alloy containing 4.3 per cent carbon is greatly modified by gradual increments of silicon. The capacity of the iron for carbon is, to some extent, affected by phosphorus, but it appears to be only to the extent to which iron is withdrawn to combine with the phosphorus. Free carbon affects the properties of the iron not only in accordance with the amount present, but also according to its physical condition and the manner of its distribution. The carbide is separated during cooling, and is dissociated according to the amount of silicon which is present. In iron containing much silicon the decomposition is virtually complete, and there is left a matrix of a solid solution of silicide of iron in iron, in which the graphite plates are embedded.

The size of the graphite plates depend upon the degree of diffusibility of the substances and their rate of dissociation. If the cooling be very slow, the period of free diffusion and concentration is prolonged, and this permits of the formation of large plates of

cementite, which in turn produce large graphite plates. Uniformity of diffusion and dissociation is necessary to the formation of small and evenly distributed graphite particles, so as to insure that there shall be the minimum interference with the strength and physical properties of the iron.

Having considered the problem of increasing the strength of irons by reducing the planes of graphite weakness, we next have to consider how, when the graphite has been reduced to such a degree as to leave machinable iron, we can increase the strength of the pearlite matrix in which the graphite is embedded.

Phosphorus and Sulphur.—The increased strength of the pearlite matrix can be brought about by various means. The first is the elimination of impurities, such as phosphorus and sulphur. Both of these materials are hardening agents, but as the percentage increases, brittleness comes in. For high tensile cast iron it is necessary to eliminate phosphorus. The phosphorus content cannot be removed in the cupola, and hence low phosphorus iron should be used. With very little phosphorus present in castings the tensile strength will run 35,000 to 40,000 pounds per square inch, provided the graphite also has been simultaneously corrected. The elasticity as shown by the bending test, however, increases considerably. For similar reasons it is necessary to reduce the sulphur content below 0.08 per cent.

The affect of the addition of special elements to gray cast iron has received a fair amount of attention during recent years. Smalley, for one, has investigated the influence of a number of different elements on the strength of cast iron. These elements investigated, which we will now consider in turn, are manganese, chromium, nickel, chromium-nickel, tungsten, molybdenum, vanadium, copper, tin, aluminum and titanium.

Manganese, it has been shown, increases both the tensile strength and hardness in proportion to the percentage used. As the amount of combined carbon remains practically the same, it has been suggested that the increase in tensile strength of high manganese iron is due to a matrix change, namely, the pearlite changing to sorbite. The shrinkage increases with increasing manganese content. The casting properties of such iron, including fluidity and freedom from gases, are good, and sound castings are obtained.

Chromium.—The earliest work on the influence of chromium on cast iron is that of Kup, who experimented on gray cast iron with chromium additions up to two per cent. His results show a slight increase in strength up to one per cent, then a decrease. The shrinkage was increased when less than one per cent was added. Campion, in a later investigation, found that one per cent of chromium increased the strength and hardness and also the proportion of combined carbon. Hurst states that in a cast iron containing one per cent of silicon an addition of 0.9 per cent chromium rendered the fracture perfectly white, and that drastic annealing at 1650 to 1740 degrees Fahr. (900 to 950 degrees Cent.) failed to produce graphite. He also states that increasing the silicon content tends rapidly to reduce the stability of the carbide. A cast iron containing 3.15 per cent silicon and 6.94 per cent chromium gave a Brinell hardness of 440 on a sand cast iron. The same alloy containing 1.46 per cent silicon was glass hard and white. With chromium additions to ordinary gray cast iron and cylinder iron, even such small proportions as 0.11 per cent and 0.15 per cent increased the strength and hardness slightly, while with larger addition of 0.78 per cent to the ordinary iron the tensile strength fell. The transerve strength was little affected, and the Brinell hardness increased. A similar addition of chromium to the cylinder iron produced an increased transerve strength and Brinell hardness, but little change in the tensile strength. Piworsky's experiments show that with up to 0.5 per cent of chromium the strength and shock-resisting properties of cast iron are increased to the extent of about 10 per cent, while the hardness increases from 20 to 25 per cent. Donaldson's investigation, carried out on a good cylinder iron with chromium additions of 0.19 and 0.39 per cent, show an increase of 5 and 10 per cent in the strength, and 5 and 11 per cent in the Brinell hardness. Summing up the results of those investigations, it appears to be definitely established that 0.5 per cent chromium in the presence of about 2 per cent silicon increases the tensile and transverse strengths and the hardness of gray cast iron. This increase in strength is brought about by the chromium preventing the formation of graphite and producing a more stable double carbide of iron and chromium which crystallizes out with the pearlite.

Nickel.—Experiments on the influence of nickel on gray cast

iron have been numerous. Kup added metallic nickel up to 0.75 per cent to a gray machinery iron, and came to the conclusion that no advantage could be expected from small additions of this element. Guillet found that nickel caused precipitation of graphite, that pearlite disappeared as the nickel increased, and that cementite became more or less acicular in form. Thaler stated that the addition of 1 per cent of nickel caused the separation of 50 per cent of the graphite, and with further additions of nickel up to 48 per cent, graphite gradually increased until 85 per cent of the total carbon existed as such. Hatfield also expressed the opinion that the precipitation of graphite is facilitated by nickel, and that the nickel at the same time acts as a softener, but it useful in no other direction. Campion found that by adding 1 per cent of nickel to gray cast iron the graphite was increased from 2.54 to 2.77 per cent; also that there was an increase in strength but a decrease in hardness. Smalley's grain-refining experiments show that 0.5 per cent of nickel has a densening effect on the structure of gray cast iron. Such a quantity, however, does not affect the hardness. The experiments of Piworsky confirm the influence of nickel in producing graphitization. They also show that a moderate nickel content of 0.5 per cent to 1 per cent improves the mechanical properties of gray cast iron by 20 to 30 per cent. With a higher content up to 2 per cent, owing to too favorable graphitization, a falling off takes place. This improvement of the properties by nickel is attributed to mixed crystal formation with the iron. An investigation on the combined effect of chromium and nickel showed that certain relative proportions of these elements increased the tensile and transverse strengths, as well as the hardness and compressive strength, without diminishing the resistance to shock and deflection. It was shown that in the presence of chromium, nickel has nothing like such a powerful affect in precipitating graphite as when present alone.

Tungsten.—The influence of tungsten on cast iron was first investigated by Campion, who found that 1 per cent of tungsten increased the strength but reduced the hardness. He also stated that 1.5 per cent of tungsten added to a gray iron containing combined carbon 0.65 per cent, graphitic carbon 2.70 per cent, and manganese 0.5 per cent, raised the tensile strength from 24,000 to 35,270 pounds per square inch. In another case the result was 44,150 pounds per square inch with 1.28 per cent tungsten, against 27,155 pounds

in the ordinary iron. Thus, 0.5 per cent of tungsten favorably influences the mechanical properties of cast iron, and in addition to increasing the tensile, transverse, and compressive strengths, there is also an increase in the shock-resisting properties. The effect of tungsten on the carbon is to promote feeble graphitization, the improvement in the mechanical properties being attributed to the formation of mixed crystals of iron and tungsten, giving rise to a new structural constituent of tungsten-ferrite.

Molybdenum.—The addition of molybdenum to cast iron was first investigated by Campion, who found that 1 per cent of molybdenum increased the strength and reduced the hardness. Smalley's experiments showed that 0.1 per cent of molybdenum closed the grain of gray cast iron without appreciably affecting the hardness. The addition of 0.15 per cent molybdenum to an ordinary gray iron containing 2.2 per cent silicon, reduced the tensile and compressive strengths and the chilling power, exerted little effect on the Brinell hardness, and increased slightly the transverse strength and deflection. Increasing the quantity to 0.25 per cent slightly reduced the chilling power, increased the transverse strength and deflection, but did not affect the other properties. In the presence of 0.5 per cent of molybdenum, apart from the chilling power which is slightly reduced, all the other properties are improved, especially the compressive and transverse strengths. The effect of small quantities of molybdenum is more marked in iron containing 1.25 per cent silicon, 0.12 per cent improving the mechanical properties but reducing the chilling power. The addition of 0.24 per cent molybdenum further improved the tensile strength without affecting the hardness, or the compressive and transverse strengths. In none of the irons did the molybdenum additions affect either the fluidity or the total shrinkage. Further tests were carried out adding 1.5 per cent molybdenum to a special cylinder iron when the tensile, compressive, and transverse strengths were increased by 25, 22, and 9 per cent respectively. On common gray iron, 1.5 per cent of molybdenum exerted a similar all-around improvement, although in a lesser degree. As regards the carbon, the tendency of molybdenum is to reduce rather than increase the amount of carbide. Machining properties are affected by over 0.5 per cent of molybdenum, the iron becoming exceedingly difficult to cut. Piworsky's tests show that molybdenum produces practically the same effect on gray cast iron as does tungsten on a similar iron.

Vanadium.—As for vanadium, it has been shown that a small quantity in conjunction with tungsten or molybdenum does not produce any material benefits in gray cast iron. Kent Smith showed that with 0.15 per cent vanadium there was an improvement in the tensile, transverse, and compressive strengths. He states that the principal action of vanadium is as a scavenging agent for removing oxygen and nitrogen. Norris agrees generally with Kent Smith's conclusions, and states that vanadium exerts a strong influence in refining the grain, eliminating porosity, and promoting soundness, increased strength, resistance to wear, and rigidity. Hatfield's experiments on the heat treatment of white cast iron containing vanadium show that vanadium tends to maintain the carbon in the combined condition, and to prevent the precipitation of graphite. Campion found that 0.15 and 0.25 per cent vanadium increased the strength but diminished the hardness of cast iron. Smalley's experiments with 0.15 per cent vanadium additions do not confirm the hardening effect of this element. Unlike the previous investigator, Piworsky shows that this element produces the formation of carbide. The effect of vanadium appears only with additions of over 0.5 per cent, and then very suddenly and is most marked in the lower silicon irons. The transverse and compressive strengths increase, also the hardness, which is increased to such an extent that the irons can no longer be regarded as commercial irons.

Titanium.—Early experiments with titanium show that the small addition of 0.05 per cent of this element increases the transverse strength of cast iron, but that larger additions produce no further advantage. Piworsky's recent investigations confirm this finding, 0.1 per cent of titanium producing maximum graphitization.

Copper.—Investigating the influence of copper on cast iron, Lupin concluded that while the addition of the element was not beneficial, its presence had at the same time no detrimental effect. There was a slight graphitization effect on the carbon, and the tensile strength increased from 40,000 to 45,000 pounds per square inch with 4.9 per cent of copper. Smalley found that the addition of 0.5 per cent copper tended slightly to increase the hardness, although there was a slight decrease in the combined carbon. Hamasumi found that with copper additions up to 4.0 per cent there was a steady increase in the tensile strength and Brinell

hardness, and the alloy appeared to be rather tough. As regards the effect on the carbide, only erratic results were obtained.

Guillet investigated the influence of tin on gray cast iron, and found that this element considerably increases the hardness of the iron, and that the hardness is maintained at high temperatures. Hamasumi's tests with up to 6 per cent tin show that up to 2 per cent it increases the strength and hardness slightly, but with over 2 per cent the iron becomes hard and brittle.

Aluminum.—Experiments with aluminum by Malland and Waldron show that the influence of aluminum on cast iron up to 0.5 per cent is similar to that of silicon. The total carbon is reduced, and the graphite precipitated. Additions of aluminum over 0.5 per cent produced a reversion, the carbide becoming more stable, and it was suggested that this was due to the formation of a double carbide of iron and aluminum. Recent tests by Piworsky do not confirm this, additions of aluminum up to 0.8 per cent producing graphitization. In the presence of low silicon there is an increase in the transverse strength and shock-resisting properties, but a considerable decrease in the hardness and compressive strength.

Pearlitic Cast Iron

Having discussed the influence of these various elements, the next problem to be considered in the producing of high tensile strength cast iron is that of the metallographic structure of the ferrite. In the course of research work, some years ago, investigating the possibility of producing malleable cast iron with a tensile strength of the order of 45,000 to 50,000 pounds per square inch without the use of the annealing process, irons were made with a view to producing pearlitic structure, or pearlitic cast iron. In these irons the weak graphite planes were reduced and also the ferrite matrix strengthened by increasing the combined carbon, so that the structure on cooling consisted of pearlite and graphite. Iron of this kind has been made on a large scale, with a tensile strength of 45,000 pounds per square inch in thickness of sections of 1.5 to 2 inches. It is readily forgeable, and has considerable elasticity, about 0.3 per cent elongation, and takes a permanent set on the bend test machine.

Requirements.—The essential facts in producing pearlitic cast iron are: first, the graphite must be reduced in quantity and in size

as flakes; second, the phosphorus must be reduced to practically negligible limits, as it induces weakness in the pearlite; and, third, the silicon content must be so adjusted that the combined carbon in the finished casting is not excessive for the thickness of the metal being cast. The percentage of combined carbon, however, may vary between fairly wide limits, and pearlitic irons have been made with 0.55 to 0.89 per cent of combined carbon. A specimen of metal having a combined carbon of 0.56 per cent exhibited under the microscope an all-pearlitic structure at the high magnification of 600x. Additional, slow cooling in the mold is essential to avoid chilling. Hence, the desirability of a hot mold, but this again is a function of the weight of metal to the weight of molding sand, and not in itself a special factor, but only a relative one.

Properties.—The production of pearlitic cast iron has been approached from different points of view. German advocates of this material evidently attached chief importance to wear; whereas in England it has been approached on a large scale from the point of view of increased strength of the material and resistance to cracking when the material was subjected to high stress at a high temperature. It has been known for a long time that one of the strongest structures in steel is a pearlitic one, and, therefore, it was deducted that stronger irons would be produced by having an entirely pearlitic structure, with graphite present as the only other constituent. This graphite, as far as possible, should be as finely divided as possible. It is easy to produce the pearlitic structure, provided the question of cost does not enter into the matter, but it is not so easy to produce the graphite in an entirely non-flake or spheroidal form. The German patent does not make any attempt to control the form of the graphite. It is a question of commercial interest to know when it will be worthwhile to manufacture castings in pearlitic cast iron. In all cases where strength is the chief requirement it will pay to ensure the increased cost of manufacturing castings in this material.

To understand definitely what pearlitic cast iron really is, one must closely examine what takes place when molten iron solidifies. Cast iron cannot be said to have a solidification point, but rather a range in which the different constituents solidify out. The analysis, mass effect, latent heat, and rate of cooling, all govern the length of this range. The lower the percentages of impurities in cast iron

the shorter the range, and higher the temperature at which solidification commences.

At about 2264 degrees Fahr. (1240 degrees Cent.) cast iron begins to solidify, and just immediately afterward the iron carbide, which is not very stable in the solid form at high temperatures, starts to split up, forming primary graphite and ferrite, the latter depending upon the composition of the iron. The amount of graphite thrown out of solution depends on the amount of carbon, silicon, phosphorus, manganese and sulphur, as well as the rate of cooling, the first two constituents and the latter condition having the greater effect.

The rate of cooling is governed by the size and thickness of the casting, the casting temperature, temperature of the mold, the latent heat of the iron employed, and the conductivity of the sand. Cooling continues down to about 1725 degrees Fahr. (940 degrees Cent.) when the phosphide eutectic solidifies. This point is the end of the solidification range. The amount and condition of the phosphide present is governed by the amount of phosphorus in the iron and rate of cooling. Being the last constituent to solidify out, it naturally tends to segregate into patches; but if the percentage is low and the existing conditions favorable, it draws into a meshwork formation around the crystal boundaries of the iron. To obtain this desired condition, the rate of cooling must not be too slow. Secondary graphite still continues to be formed right down to about 1380 to 1290 degrees Fahr. (750 to 700 degrees Cent.), but cannot grow very large owing to the material being completely solid.

The remainder of the carbon in the iron which has not been thrown out as graphitic carbon and is still combined with the iron, is left as pearlite. This pearlite consists of alternate layers of ferrite, which is almost pure iron, and cementite, which is iron carbide in the proportion of seven of ferrite to one of cementite, the whole having about 0.9 per cent carbon unless other elements are present to affect this.

Methods of Producing.—It can readily be seen from the foregoing facts that quite a number of changes in the ultimate structure of the iron can be made by slight variations of structural analysis and rate of cooling. Advantage of this fact is taken in the production of pearlitic cast iron. Pearlite and graphite are very closely

associated with each other in cast iron. Often in poor iron there is a layer of silicon-ferrite separating them, but under specially controlled conditions it is possible to obtain a wholly graphitic and pearlitic structure without any free ferrite being present. This can only be accomplished by working to very fine limits as regards the actual analysis of the cupola mixture, melting losses, the conditions during the passage of the iron through the cupola, the ultimate analysis and the rate of cooling through the critical stage, if castings of a definite mass and size are to be produced.

The mass having a very large effect on the ultimate structure, it is claimed in the Thyssen-Emmel process, that no matter what mass is cooled it is pearlitic. This process and the Lanz process for producing pearlitic cast iron have been recently brought before the foundryman's attention.

The Lanz-Perlit process depends for its successful results upon: first, the proper preheating of the mold to a given temperature; second, the correct chemical composition of the iron relative to the mold temperature; third, the correct variation of either or both of the above, concomitant with the thickness of a section of the casting. If these fundamental principles be strictly carried out, with details provided in the license for using the process, special benefits and results as follows are claimed:

1. The matrix of the structure will be all pearlite.
2. This matrix will prevail equally throughout a casting of complicated section.
3. Pearlite structures produced by this process are superior to those obtained by other means.
4. The pearlite structure developed by employing this process is associated with a graphite structure better than usual.
5. Irons of extremely low silicon content may safely be used, and an entirely gray fracture free from any chill, very uniform and close-grained in all sections, is guaranteed.
6. In short, a material results which is possessed of far better properties than ordinary cast iron, a material upon which the engineer can safely rely and base his calculations.

As for the Thyssen-Emmel process, statements show that the special properties claimed for the cast iron made by this process are due to: first, a special modification to the working of an ordinary cupola whereby coke to iron ratios far lower than usual are possible; second, the increase by the above means of the silicon

content in definite relationship to the lowering of the total carbon, in order to effect a requisite graphite separation. Subsequent to tapping from the cupola, no treatment either to metal or molds, beyond that common to all foundry practice, is necessary to fulfill the following claims:

1. A guaranteed total carbon content of under 3.0 per cent.
2. Uniformity of section throughout complicated and thick castings.
3. An all pearlite matrix to the structure for all sections.
4. No free cementite or ferrite in any part.

The effect obtained by preheating the mold by the Lanz process can also be obtained by casting at a very high temperature into a warm mold, as the mold being warm avoids a sudden chilling action of the metal when entering it.

The pearlite formed can be of a coarsely laminated nature, or a fine unlaminated condition, depending again mostly upon the silicon content and the rate of cooling. Sorbite is the name given to this unlaminated pearlite when not able to be resolved at the highest magnifications, and it is the most desirable condition in cast iron when accompanied with small, fine, curly graphite. To obtain this ideal structure, an iron having a low silicon, phosphorus, and total carbon content, must be used. Owing to the effect of the other constituents of cast iron and the rate of cooling upon the condition of the carbon, total carbon should not be above 3.2 per cent, or large, straight-flake graphite is likely to be formed. Phosphorus should not be above 0.2 per cent, owing to its tendency to segregate.

Casting with a high percentage of superheat, and the subsequent fairly slow cooling through the critical stage, even a small percentage of phosphorus is likely to segregate. When this happens, the resulting iron does not give such high physical tests as when the phosphide is in the most desirable meshwork formation. Moderately high manganese is desirable, but not essential, so long as there is enough present to look after the sulphur and help the stability of the pearlite, since the effect of the manganese remains to help hold the carbon in the combined state. Sulphur is usually fairly high in low-silicon irons, but this fact does not seem to have any detrimental effect on pearlitic cast iron up to about 0.13 per cent. The fact that casting very hot is an essential condition in its production may account for this.

When investigating the physical properties of cast iron suitable

for internal combustion engine castings, one must consider the conditions to which the castings are subject. The three most important of these conditions are high temperatures, repeated impact, and hard wear. Any discussion of the resistance of cast iron to high temperatures should take into consideration the cause of growth. The most potent cause of growth in cast iron is usually the presence of large graphite flakes in the free ferrite of the metal structure. Free ferrite, which is silicide of iron in solution, when present in cast iron is in the vicinity of the graphite, and the hot gases burn out the graphite, which gives access to the free ferrite thus attacked and oxidized into silica and iron oxide. Owing to these substances having a larger volume than the substance from which they are formed, the sides of the cracks open slightly, and growth results.

In conjunction with high temperatures existing in an internal combustion engine, the repeated impact of the explosion calls for a tough, strong iron. The two chief weaknesses of cast iron are graphite and phosphide, the graphite being a non-metallic substance filling up small cavities. The phosphide when in large percentages forms into patches which are very brittle, and so lowers resistance to the impact.

An iron which has to stand up to hard wear must be free from large-flake graphite and free of any substance of a soft nature in its structure, such as free ferrite. This sums up the points to be avoided in iron suitable for internal combustion engine castings, and leaves us with pearlitic cast iron as having none of the defects stated previously. From this we must conclude that at the present time pearlitic cast iron is the best iron for high duty work.

PRODUCTION TESTS OF CARBURIZING COMPOUNDS

By J. S. Ayling

Abstract

The author has briefly described a short, concise and inexpensive method of testing the relative merits of various carburizing compounds under actual production conditions as used in any heat treatment department. While this method does not include all of the laboratory methods of examination of the finished material, it does give a comprehensive and practical figure as to the merit of any carburizing compound in respect to any other compound as used in actual practice under individual shop conditions. Should the investigator care to extend his tests into exhaustive metallographical or physical tests he has the necessary test bars or production parts upon which to work.

It is pointed out through figures obtained in a test similar to the described one that the cost of a carburizing compound is not the guiding consideration in the production of carburized parts.

Procedure

EQUAL weights of the various carburizing compounds to be tested (1000 pounds or one ton is recommended) are placed in separate bins or containers, and each carburizing material kept separate from the others throughout the test.

All compounds should be placed in production under the supervision of the person conducting the test and each compound should be used on the same kind of work, i. e., if bolts are being carburized one day, all compounds should be used on bolts; if gears are being carburized the next day, all compounds should be used on gears. It is advisable to run tests using one or two carburizing furnaces and loading the same number of boxes of each compound in the same heat. Adjacent boxes after charging should be of different materials marked so as to prevent them from becoming mixed and their relative positions should be reversed on succeeding heats. This method will tend to equalize any variation in furnace condi-

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tions. Obviously, the furnace selected should heat as uniformly as possible at all points so that any one container is not heated more rapidly than any other in the same heat, because temperature has a marked influence on the speed of penetration and percentage of carbon absorbed. For average steels a temperature of 1650 to 1700 degrees Fahr. is recommended.

Test pieces of the same kind of steel as is being carburized should be packed in each box. These can be used to check the depth of case and speed of penetration and any other tests that are required.

When heats are out and the carburizing material cooled, the dust, scale, etc., is screened out of the carburizing compound, using the material saved from screening as a base for the second run. This material should be placed in bins or containers under its correct classification.

The work from the first run should be kept separate, hardened, finished and inspected, noting the number and weight of pieces and the percentage of rejections, if any, from the lots carburized in the different compounds.

The second run is started by adding enough new compound to the base from the first run to make up the shrinkage and loss from screening. This usually requires about 20 to 30 per cent new material. The boxes are repacked as in the first run. Test pieces are checked and the carburized parts are hardened, inspected and weighed as before. This method is followed out on successive runs until the initial weight (1000 pounds or one ton) of each carburizing compound is used up. This procedure will furnish the following data for each compound tested:

1. Gross weight of steel carburized per ton of carburizing compound.
2. Per cent rejection due to defective carburizing, such as non-uniform case, soft spots and insufficient depth.
3. Indirect balancing of rate of penetration (percentage of carbon roughly obtained by visual inspection of fractured test bar).*

Analysis of Results

In balancing the above data, the quantity of satisfactorily car-

*Any compound showing increased penetration rate may result in a shortening of carburizing time, resulting in a saving of furnace time and fuel, etc.

burized parts usually has the greatest influence on the cost. The following examples will demonstrate:

Assuming that 19 tons of carburized parts per ton of compound are produced and that the steel, after machining and carburizing, costs at least 10 cents per pound, or $3800.00, a compound having 1 per cent lower rejections than another saves $38.00 per ton of compound used. The first material is then worth $38.00 per ton more than the second, other factors being equal. Lowest percentage of rejections should, therefore, be the primary factor considered. By combining the cost of the carburizing compound used and the cost of the spoiled material carburized, a definite comparison is easily obtained as to the practical production value of the various carburizing compounds tested. The following example taken from a test of four materials will show how the above data was considered in arriving at the practical production value of the four materials tested.

Compound	Price per ton for carburizer	Number pounds steel carburized per ton of carburizer	Weight of rejections	Per cent rejections
A	$60.00	36,050	721	2
B	69.50	41,500	207	0.5
C	80.00	35,100	351	1
D	55.00	32,500	975	3

Compound A—Figuring 2 per cent rejections and an average cost of 10 cents per pound for steel, the loss from defective carburizing can be figured 2 per cent of 36,050x10 cents per pound = $72.10 in rejections per ton of carburizer used. $72.10 loss plus $60.00 first cost of carburizer = $132.10 real cost of carburizer. The cost of $132.10 divided by the number of pounds of steel carburized (36,050 pounds) gives 0.366 cents, which is the cost for the carburizing compound per pound of steel carburized.

Compound B

10 cents x 41,500 x 0.005 = $20.75 loss in rejections
69.50 carburizing compound cost
$90.25 real cost of compound

$\frac{\$90.25}{41,500}$ = 0.217 cents, cost of carburizer per pound of steel carburized.

Compound C

10 cents x 35,100 = $ 35.10 loss in rejections
80.00 carburizing compound cost
$115.10 real cost of compound

$$\frac{\$115.10}{35{,}100} = 0.325 \text{ cents, cost of carburizer per pound of steel carburized.}$$

Compound D

10 cents x 32,500 x .03 = $ 97.50 loss in rejections
55.00 carburizing compound cost
$152.50 real cost of compound

$$\frac{\$152.50}{32{,}500} = 0.469 \text{ cents, cost of carburizer per pound of steel carburized.}$$

A summary of the preceding data is as follows:

Compound	Cost of carburizer per pound of steel carburized	
	Gross*	Net*
A	$0.00366	$0.00373
B	0.00217	0.00218
C	0.00325	0.00331
D	0.00469	0.00483

From the above it is obvious that compound B was the most economical carburizing compound to use, although both A and D were cheaper materials in the first cost. Compound C, while the highest priced, was inferior to B, but more economical than either A or D.

The inspection of test bars also showed B to give the most uniform penetration and slightly deeper than C. Compound D was very nonuniform which may account for its greater percentage of rejections. It was also the first to be used up. The greater tonnage produced by B was attributed to the fact that it was the lightest in weight and naturally the initial weight set aside was the greatest volume and lasted longest. In this test the work produced during the test consisted of piston pins, spring bolts, and other bolts, all of which were ground after hardening and required to have a minimum scleroscope hardness number of 75.

The temperature used for carburizing was 1650 degrees Fahr. and the time in the furnace was approximately the same for all heats.

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* Gross cost refers to the cost of carburizer per pound of steel carburized including the weight of rejected parts.
Net cost refers to the cost of carburizer per pound of steel carburized excluding the weight of rejected parts.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

THE CONSTITUTION OF STEEL AND CAST IRON
SECTION II—PART IV

By F. T. Sisco

Abstract

This installment, the fourth of the present series, discusses some of the variations usually included under a description of annealing. As was the case in former installments these different forms of annealing are discussed from the standpoint of their structural changes and the relation between these changes and stable or unstable equilibrium. The most important item is annealing below the critical range used extensively for cold-worked steel products such as wire, sheet, tubular products and the like. Other variations in annealing discussed are the annealing of alloy steels, the patenting of wire, annealing of steel castings and the graphitization of malleable iron. The discussion of annealing is concluded by a summary.

IN OUR previous discussion of the structural changes accompanying the operation of annealing we have, first of all, outlined the general principles involved in this thermal treatment; after that we viewed specifically the structural changes taking place in annealing plain carbon steels, and following this, the changes occurring in normalizing and spheroidizing. The discussion of these three phases has by no means covered all of the different thermal treatments included in the general term annealing. One important branch is annealing below the critical range, applied usually to cold-worked steels. This form of annealing is used not

This is the fourteenth installment of this series of articles by F. T. Sisco. The several installments which have already appeared in TRANSACTIONS are as follows: June, July, August, September, November, 1926; January, February, April, June, August, October, 1927; February, April, 1928.

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only to produce a desirable structure and the required properties in the finished product, but in many cases is also absolutely essential to the process itself.

In addition to annealing below the critical range there are several miscellaneous annealing operations which deserve mention. Most of these cannot be described under annealing of carbon steels, normalizing, spheroidizing, or annealing below the critical range; either because their structural changes are different as in the graphitization of cementite in malleable iron, or because they occupy a special niche in the processes of which they are a part, as in the annealing of steel castings, the patenting of steel wire and the like.

Structural Changes in Annealing Cold-Worked Steels

There is a large class of commercial steel products that, in the last stages of their mechanical treatment, are worked at temperatures below the critical range. In this class are wire and rods, cold drawn and cold-rolled; tubular products, sheet, and many others. The effect of working steel below the critical range is to distort severely the normal grain structure. This distortion is especially evident if the material is worked at atmospheric temperature as in wire drawing. Wire is often reduced as much as 40 per cent in cross section at one draft. The strains set up in this drastic cold working are very severe and if not relieved would result in so much brittleness that the wire would tear apart after the third or fourth passage through the dies.

As an example of the brittleness due to grain distortion and the hardness imparted by cold work the following may be cited: A No. 5 Bessemer rod, diameter 0.2066 inches has average properties of 74,000 pounds per square inch ultimate strength and 17.0 per cent elongation in ten inches. After three drafts to a No. 13 wire, diameter 0.0909 inches, the ultimate strength has increased to 142,000 pounds per square inch and the elongation has been reduced to 0.5 per cent in 10 inches. One draft of this No. 5 rod to 0.1607 inches reduces the elongation from 17.0 to 1.3 per cent.

In order to complete drafting operations on small sizes, the wire must be annealed at intervals during the process. This annealing consists of heating the coils in closed pots to temperatures ranging from 850 to 1200 degrees Fahr. The length of time the

wire is held at the specified temperature and the method of cooling are learned by experience. The object of this annealing is to relieve the strained condition and, by promoting recrystallization of the distorted grains, make the material ductile so it will withstand further cold work.

Wire is not the only cold-worked material that is annealed. Thin sheet and tubular products must also be annealed, often more than once during processing, and usually after the final rolling or drawing. Sheet is annealed after the final rolling to permit cold forming and stamping operations to be carried out successfully.

We have repeatedly emphasized that there is no structural change in heating a normal steel to any temperature below the lower critical point. In other words if a steel has been slowly and uniformly cooled from a high temperature so that it approaches in structure a condition of stable equilibrium, repeated heating and cooling to any point below the critical range will not change the structure.

We have considered lamellar pearlite to be relatively stable but we have done this simply because it is the form of pearlite usually encountered in commercial annealing processes. It is the characteristic form of pearlite. Actually, globular or spherical cementite is more nearly stable than the thin plates but in order to attain this more stable structural condition we have to use special methods which involve putting the pearlite first in a more unstable form, i. e., sorbite, granular pearlite or finely lamellar pearlite. If we did not do this the speed of reaction to spheroidize would be so slow that it would be commercially impracticable. Spheroidizing is a change in structural condition at or below the lower critical point but it takes place at this temperature solely because the structural condition is not stable to start with; hence it does not conflict with an original statement that heating a normal steel below the critical range does not affect the structure.

In annealing cold-worked steel below the critical range we have an entirely different condition. Here we have grains that have been mechanically distorted; they have been pulled and squeezed and hammered and battered until they are all out of shape and bear no resemblance to their normal selves. It is even possible that some of the crystals have been destroyed and amorphous metal formed. The structure of such a steel is shown in Fig. 28, a photo-

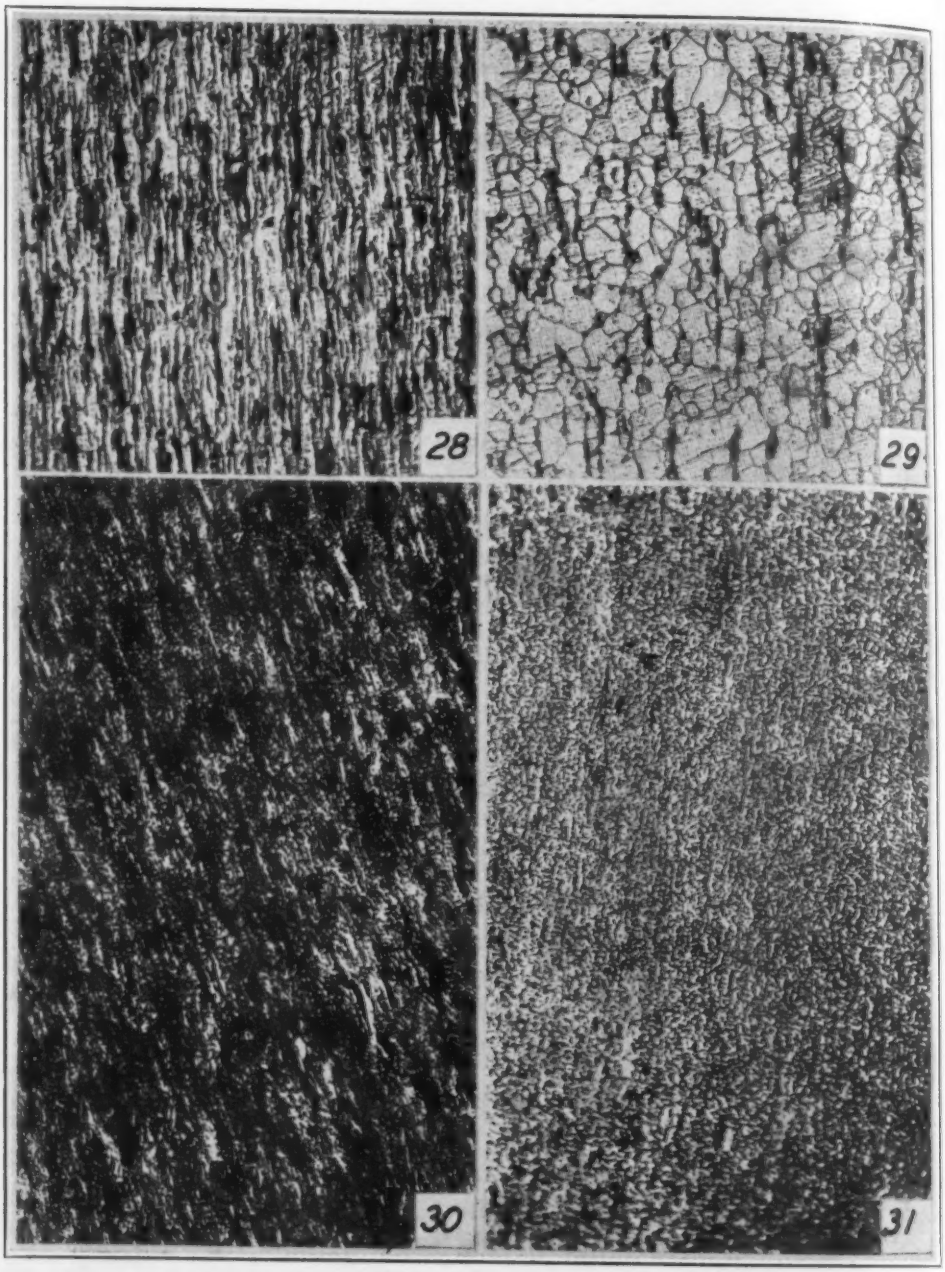


Fig. 28—Photomicrograph of Steel Wire, 0.08 Per Cent Carbon, Cold Drawn. Mag. 100x (E. H. Peirce) Fig. 29—Photomicrograph of Steel Wire, 0.08 Per Cent Carbon, Cold Drawn and Reheated Below its Critical Range. Mag. 100x. (E. H. Peirce). Fig. 30—Photomicrograph of Aircraft Streamline Wire, 0.40 Per Cent Carbon, Cold Drawn. Mag. 500x. Fig. 31—Same as Fig. 30, Reheated to 1100 Degrees Fahr. for 1 Hour. Mag. 500x. All Specimens Etched in Alcoholic Nitric Acid.

micrograph of an 0.08 per cent carbon steel, and Fig. 30, a photomicrograph of a 0.40 per cent carbon steel.

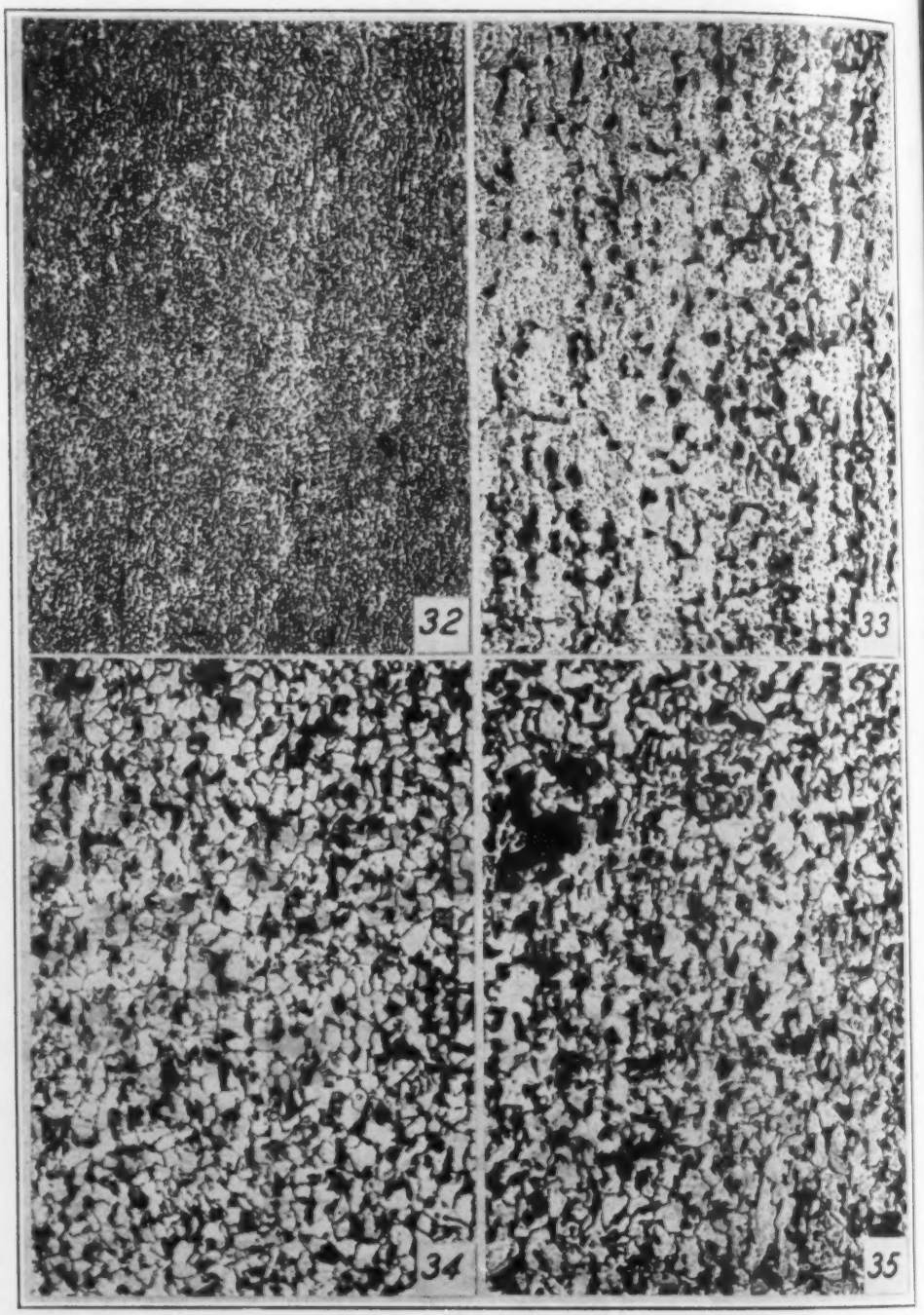
This distorted condition of the grains is extremely unstable, almost as unstable as a hardened steel. It follows that there will be a return of the grains to stable equilibrium at the first opportunity. As soon as sufficient mobility is attained through the action of heat the grains will attempt to rearrange themselves into their normal shape and size. We could produce this recrystallization almost immediately by heating to a high temperature and slowly cooling, but we can also do it—although it takes longer—at temperatures well under the critical range.

Recrystallization below the critical range takes place fairly rapidly in very low carbon steels. The temperature of the reaction for ferrite is given as about 965 degrees Fahr. (520 degrees Cent.). As a result much of the cold drawn wire made is "process"[25] annealed at temperatures varying from 900 to 1150 degrees Fahr. Fig. 29 shows a low carbon steel cold-worked and annealed below the critical range.[26] In comparing with Fig. 28 it will be noted that the white ferrite grains have recrystallized and assumed their normal form. It is also evident that the dark pearlite grains have not recrystallized completely. In Fig. 29 they are still elongated. From this it follows that it is more difficult to anneal below the critical range a steel containing considerable pearlite—for example 0.40 per cent carbon equivalent to 50 per cent pearlite—than a very low carbon steel where the structure is mostly ferrite. The changes in structure on annealing such a cold-worked steel are shown in Figs. 30 to 35 inclusive. Fig. 30 is a specimen of aircraft wire, severely cold-worked. Its structure is typical. Figs. 31 to 35 show the effect of reheating this wire for one hour to the temperatures indicated. All of the specimens were held at the specified temperature for 1 hour followed by cooling in air.

The lower critical point in heating for a 0.40 per cent carbon steel (Ac_1) is approximately 1325 degrees Fahr.; the upper critical point (Ac_{3-2}) is approximately 1430 degrees Fahr. After heating to 1100 degrees Fahr. (Fig. 31) the very small elongated particles

[25]Process annealing is a rapid annealing given at some step in the process to distinguish it from annealing the finished product.

[26]Fig. 28 and 29 by E. H. Peirce—From Sauveur, Metallography and Heat Treatment of Iron and Steel, 1926, page 203.



A Series of Photomicrographs Showing the Effect of Annealing on the Structure of a Cold Drawn Medium Carbon Steel. Fig. 32—Photomicrograph of Same Sample as Fig. 30, Reheated to 1200 Degrees Fahr. for 1 Hour. Mag. 500x. Fig. 33—Same as Fig. 30, Reheated to 1300 Degrees Fahr. for 1 Hour. Mag. 500x. Fig. 34—Same as Fig. 30, Reheated to 1400 Degrees Fahr. for 1 Hour. Mag. 500x. Fig. 35—Same as Fig. 29, Reheated to 1500 Degrees Fahr. for 1 Hour. Mag. 500x. All Specimens Etched in Alcoholic Nitric Acid.

of ferrite so evident in Fig. 30 have almost disappeared. Fig. 32 shows the ferrite just beginning to collect into grains. Heating to 1300 degrees Fahr. (Fig. 33) or just under the Ac_1 point has served to accelerate the recrystallization of the ferrite. At this temperature the pearlite has also gathered into rounded particles, almost perfect grains. Heating to just below the Ac_{3-2} point, 1400 degrees Fahr. (Fig. 34) has developed easily discernible grain boundries but has not destroyed the last traces of cold work as evidenced by the remnant of a banded structure. These last traces of cold work have disappeared in Fig. 35 which was heated to 1500 degrees Fahr.

The above structures were obtained by heating for one hour at the specified temperature. The wire was oval-shaped and measured 0.445 inches across its major axis and 0.113 inches across its minor axis. No doubt, the same structural condition could have been obtained at lower temperatures by prolonging greatly the time of heating; for example to 6 to 7 hours.

Krivobok has done much work on the recrystallization and grain growth of ferrite below the critical range.[27] He finds a transformation point appearing in cold-worked metal at approximately 1200 degrees Fahr. This thermal disturbance disappears after the material is once heated through this temperature. This point apparently marks a sudden change of internal energy resulting from a relief of internal strains which in turn causes recrystallization. In the sample of wire just discussed the recrystallization had begun some place in the range 1100 to 1200 degrees Fahr. but was not marked until 1300 degrees was reached (Fig. 33).

It has been found by experience that a critical amount of straining in cold work produces an exceptional grain growth of the ferrite, resulting in a structure that is coarsely crystalline and brittle. In wire drawing this critical strain corresponds to a little less than 20 per cent reduction. As drafting nearly always involves heavier reductions in cross section than this, wires are usually over-strained and hence when annealed they are not too coarse in structure. The photomicrographs of Figs. 30 to 35 illustrate this. The wire has been severely cold-worked, over-strained as it were, consequently recrystallization is in small grains as is evidenced from Figs. 33, 34 and 35.

[27] Cited in Sauveur loc. cit. page 277. See also TRANSACTIONS, American Society for Steel Treating—Vol. 8, December, 1925, page 703.

Structural Changes in Miscellaneous Annealing Operations

In closing the discussion of annealing we will view for a moment a few miscellaneous annealing operations not already described. This discussion will include the structural changes taking place in annealing some of the more common alloy steels, the annealing of steel castings, the patenting of steel wire and the graphitization of malleable iron.

Alloy Steels—A large percentage of the alloy steels made today contain chromium or some other carbide-forming alloy. When considerable of the alloy is present, carbides will be formed that are difficult to break up in ordinary annealing. As a typical steel of this class we may take the high-carbon, high-chromium ball bearing steels. These steels contain approximately 1.00 per cent carbon and 1.30 per cent chromium. The high percentage of these two elements results in the formation of complex carbides of iron and chromium. These carbides are often segregated in the hot-rolled or forged bar. A simple annealing or heating to above the Ac_{3-2-1} point will not affect the complete solution of these carbides and they can be detected in the microstructure of the annealed bar. Now if this bar is hardened these undissolved carbides will be mostly unaffected and can be detected in the martensite which results from the quenching operation. A fractured section will show the small black particles visible to the eye.

If chromium steels of this composition are heated to a point well above the Acm line (Fig. 11 or 23)—for example 1700 degrees Fahr.—the carbides go into solution. After a moderately rapid cooling such as still air most of the carbides remain in solution. This normalizing is then followed by an annealing at or just above the critical range. The carbides are now in such a form that they will go into solution when the steel is heated for quenching. The result of quenching is a steel with the fine silky grain visible in the fracture of all properly made and properly treated ball bearing steels.

In general in the steels containing alloys that form solid solutions—for example nickel— do not present the annealing difficulties that are characteristic of the chromium steels. The chromium-nickel steels likewise do not present any annealing difficulties unless the chromium percentages are relatively high.

It is not necessary to discuss alloy steels any further. Detailed

information concerning the annealing of the different classes is given in all text books and in many papers on heat treatment. It is sufficient if the reader remembers that steels containing free carbides in any appreciable amount should be normalized before annealing. If normalizing is necessary or even advisable with the high-carbon tool steels it is still more necessary with the steels that contain carbides which are still more complex or still more insoluble than excess cementite.

Steel Castings. When steel is hot-worked the grains are more or less broken up under the rolls or the hammer. In general, the finishing temperatures are not greatly above the critical range, at least not high enough to produce excessive grain growth. Because hot working in itself results in a more or less desirable structure it is usually only necessary to heat hot-worked carbon steels just above the critical point to refine the grain and anneal properly.[28]

With steel castings we have more of a problem to contend with. The metal receives no hot work whatsoever, the grains are not broken up mechanically, and if the casting is large in cross section it will solidify and cool to the critical range slowly, thus permitting maximum grain growth to take place.

Annealing by heating to just above the critical range will not break up this coarse structure. A more drastic treatment is necessary. Ordinarily castings containing 0.40 per cent carbon are heated to approximately 1650 degrees Fahr. and held for a relatively long time. Cooling is in the furnace if extreme softness is desired, or in air if it is necessary to have higher tensile strength and elastic limit. Obviously the rate of cooling is determined not only by the properties desired, but also by the thickness of cross section and the size of the castings.

Fig. 36 is a photomicrograph of a 0.30 per cent carbon steel taken from a casting in which the average cross section was 1.0 to 1.5 inches. Fig. 37 shows the structure after annealing for three hours at 1650 degrees Fahr. followed by cooling by air. The effect of the annealing on the structure is obvious. The large grains of free ferrite and pearlite have been replaced by grains of granular pearlite with a network of ferrite and with free ferrite contained in the pearlite grains.

Patenting. Some medium and high-carbon steels which are

[28] Unless the steel contains free cementite or unless the structure is extremely heterogeneous.

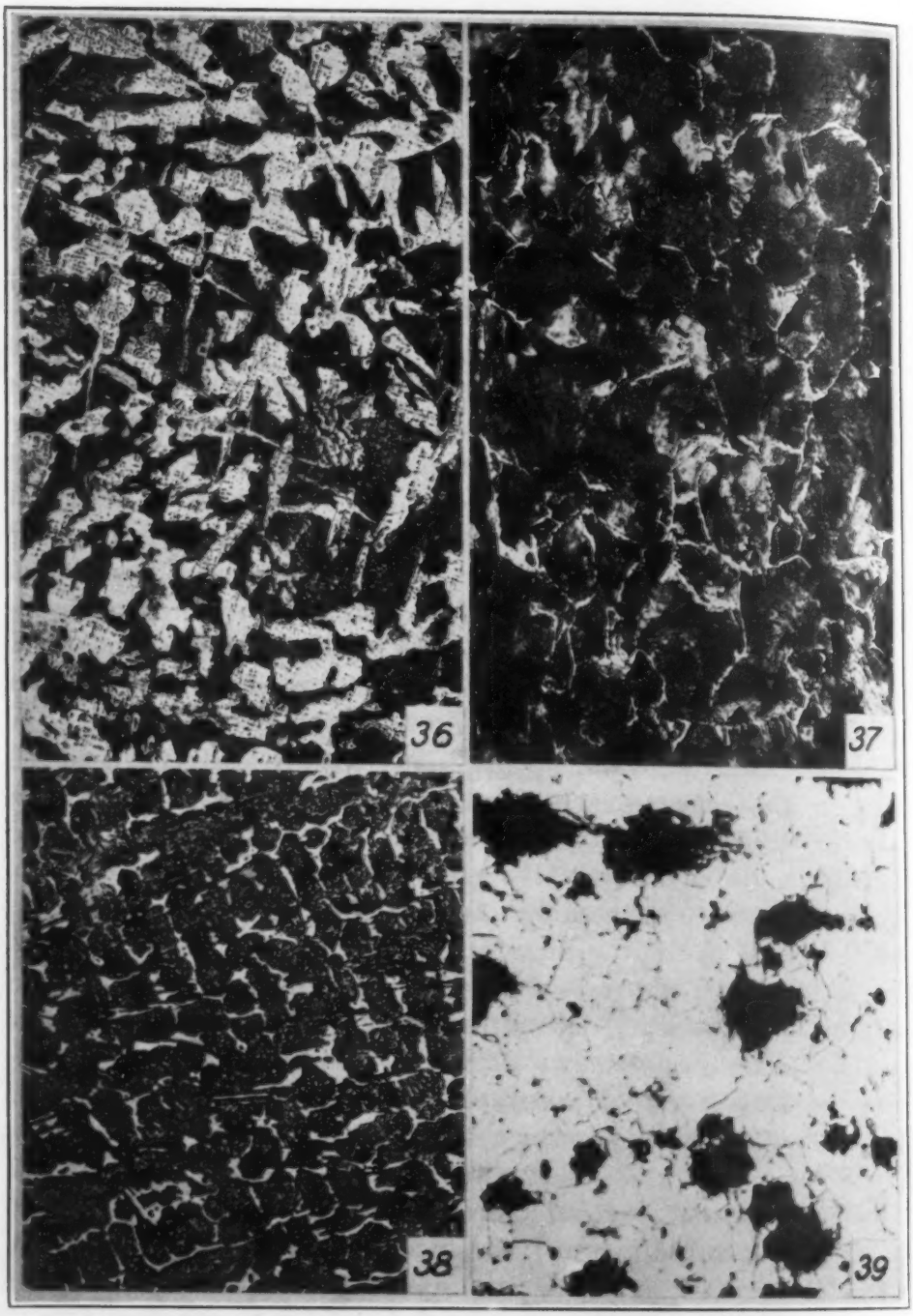


Fig. 36—Photomicrograph of a 0.30 Per Cent Carbon Steel Casting of Moderate Cross Section, As Cast. Mag. 100x. Fig. 37—Photomicrograph of a 0.30 Per Cent Carbon Steel Casting of Moderate Cross Section, Annealed 3 Hours at 1650 Degrees Fahr. and Cooled in Still Air. Mag. 100x. Fig. 38—Photomicrograph of White Cast Iron Showing Free Cementite (White); Pearlite and Proeutectoid Cementite (Dark). Mag. 100x. Fig. 39—Photomicrograph of Malleable Cast Iron Showing Ferrite (White) and Graphite (Black Particles). All Specimens Etched in Alcoholic Nitric Acid.

drawn into high-strength wire (music wire and the like) are put through a grain-refining process known commercially as patenting. In brief the process consists of heating the wire to a point well over the critical range followed by air cooling. The result is a fine uniform sorbitic structure instead of the heterogeneous pearlite of the hot-rolled rod.

Patenting is an annealing operation in which practical experience has far surpassed technical control. In order to get the best results a definite fine-grained sorbitic structure must be obtained. No pearlite should be present, nor on the other hand is it permissible to have any troostite or other harder constituent of hardened steels contaminating the sorbite.

The operation consists in passing the wire continuously through a long furnace. All of the details such as the speed of the wire through the furnace and the like have been determined by experience and the result is constancy of structure and properties not surpassed by any other heat treating operation. It is possible by the proper combination of drafting and patenting to produce music wire having a tensile strength as high as 350,000 pounds per square inch and still not have an excessively brittle wire. High strength rope and cable are made of wires processed in a similar manner.

We may define patenting as an annealing operation consisting of heating wire rods above the critical temperature followed by slightly accelerated cooling with the sole object of producing a fine-grained sorbitic structure.

Graphitization of Malleable Iron. This has been discussed in a former series of articles.[29] The graphitization depends upon four factors and proceeds more rapidly and completely: (1) if all of the carbon is combined as cementite, (2) if the temperature is high, (3) if the material is held for a long time at this high temperature and (4) if a relatively high percentage of silicon and a relatively low percentage of manganese and sulphur are present.

The composition of the iron and the melting process are so regulated that the castings as poured will be hard and will have a white fracture free from an appreciable amount of graphite. The annealing temperature is high above the critical range; 1600 to 1700 degrees Fahr. is commonly used.

[29] On the Metallurgy of Iron and Steel—Preprint No. 1, American Society for Steel Treating, page 90.

We know that a white cast iron contains two structural varieties of cementite, the cementite in solution in the saturated austenite (equivalent to 1.70 per cent carbon) and the excess or free cementite. We also know that in alloys containing less than 1.70 per cent carbon (the carbon steels) it is practically impossible to anneal so that we will have an appreciable amount of free graphite formed. Even with our slowest cooling we have a structure that consists of coarsely lamellar pearlite or in its nearest approach to stable equilibrium, divorced or spheroidized cementite. In other words, in steel, i. e., the iron-carbon alloys containing less than 1.70 per cent carbon —pearlite (or spheroidized cementite) represents our nearest approach to stable equilibrium.

We also know that the cementite in white cast iron heated under the proper conditions will dissociate almost completely into carbonless iron and graphite hence we must assume that the excess cementite present is responsible for this graphitization which proceeds so completely. It is plain, therefore, that graphitization in white cast iron and the accompanying complete stabilization in structure that results, is due, first, to the graphitization of the excess cementite present according to the reaction,

$$Fe_3C \rightarrow 3\ Fe + C$$

and following this, to the graphitization of the cementite which makes up the saturated austenite. Graphitization would be difficult if there was no excess cementite present. With this constituent, which graphitizes with relative ease, to start the process, the reaction proceeds almost to completion and our resulting structure is pure carbonless ferrite and rounded particles of free carbon (graphite).

Fig. 38 is a photomicrograph of white cast iron before annealing and Fig. 39 the resulting malleable iron.

In the production of white heart malleable iron (more common in Europe than in America), the structural changes taking place are somewhat different than in the process just described. In white heart malleable the castings are packed with an oxidizing material, usually iron oxide. The oxygen in this packing material combines with the carbon in the casting to form carbon monoxide. The result therefore is an actual removal of the carbon instead of a conversion of this element to graphite. The resulting structure

of white heart malleable iron is made up chiefly of carbonless ferrite together with a little free carbon which has escaped reaction with the oxygen in the packing material.

Summary of the Structural Changes in Annealing

Before passing on to a discussion of hardening we may, with advantage, sum up briefly some of the things we have learned about the structural changes taking place in the annealing of steel. Our whole discussion has been based on the concept that annealing, in its broadest meaning, is a process whereby the structure, through the action of heat approaches a condition of stable equilibrium. We have viewed in detail all of the various operations of annealing and can now conveniently sum up each operation on that basis.

1.—In the regular annealing of plain carbon steels containing less than 0.90 per cent carbon the steel is heated above the upper critical point, at which temperature the structure is a homogeneous solid solution or austenite. On cooling through the critical range pearlite and free ferrite (if present) are formed. The structure depends upon the rate of cooling. The most stable structure resulting from very slow cooling is one in which the grains of pearlite contain distinct, often coarse, laminations or, still more stable, a pearlite in which the cementite tends to ball-up or assume a globular form known as divorced pearlite. If free ferrite is present in large amounts, the most stable form is large, well formed grains of this constituent. The most unstable structure, resulting from relatively rapid cooling, is one in which the pearlite assumes a globular or emulsified form. No distinct lamellae can be detected. In the case of low carbon steels, this relatively rapid cooling prevents the ferrite from collecting into well defined grains, instead it appears partially as a network around the grains and as irregular, often indistinguishable patches in the pearlite. Frequently no grains of either pearlite or ferrite can be distinguished by the microscope. The structure is then known as sorbite.

2.—In the annealing of carbon steels containing more than 0.90 per cent carbon, heating to the customary annealing range affects only the structural condition of the pearlite. The free cementite is unaffected. To anneal these steels properly they must be heated above the Ac_{cm} line to affect solution of the excess cementite. They must then be cooled sufficiently fast, (as in air)

so that most of the cementite remains in solution. This process is known as normalizing and is frequently used for high carbon steels and for many of the alloy steels containing carbides. The structure resulting from normalizing is usually sorbite or finely granular pearlite and is relatively unstable. Normalizing should be followed by some sort of an annealing process.

3.—The unstable structure resulting from relatively rapid cooling from the annealing or normalizing range can be made more stable by reheating to a temperature just at or a little below the lower critical point. This is known as spheroidizing, from its action on cementite. The return to stable equilibrium upon heating to a temperature just at or a little below the lower critical point is even more complete than very slow cooling from the annealing range. This is evidenced by the balling up of the cementite resulting in this constituent assuming the form of small globules or spheroids. Spheroidized cementite, the most stable structure resulting from any commercial annealing process is very desirable for high-carbon and many alloy steels in that it has excellent properties, machines easily and causes good response to hardening.

4.—Mechanical work below the transformation range, and especially at atmospheric temperature distorts the grains and produces an unstable structural condition evidenced by high tensile strength and low elongation. Reheating a steel in which the structure is distorted to a temperature below the transformation range promotes recrystallization. The ferrite returns to a stable condition first at 900 to 1100 degrees Fahr.; it is more difficult to cause the distorted pearlite to return to a stable structure but this is accomplished by heating to a temperature of 1100 to 1300 degrees Fahr. Reheating a cold-worked steel to below the critical range is known as "annealing after cold work."

5.—Patenting is a form of normalizing used for medium and high-carbon steels which are to be drawn into high-strength wire. It is carried out in such a way that the resulting structure is a fine-grained sorbite, apparently free from pearlite or troostite.

6.—Annealing steel castings is a process consisting of heating to a temperature about 100 degrees Fahr. or more above the usual annealing range, and holding for a comparatively long time. Annealing steel castings is used primarily to homogenize the structure, relieve casting strains and replace the coarse brittle grains of ferrite and pearlite by a finer more uniform grain size. Cooling

after annealing steel castings is regulated by the properties desired, it may be very slow, in the furnace; or faster, in air.

7.—The graphitization of cementite in the production of malleable iron is an annealing process so regulated as to temperature and time, that the cementite, in which form practically all the carbon exists in the original casting, is dissociated completely into carbonless iron and free carbon. The graphitization of malleable castings is the only form of annealing that results in a complete reversion to a wholly stable structural condition. This result is only attained because the original structure was extremely unstable, making possible a complete stabilization once the reaction is started.

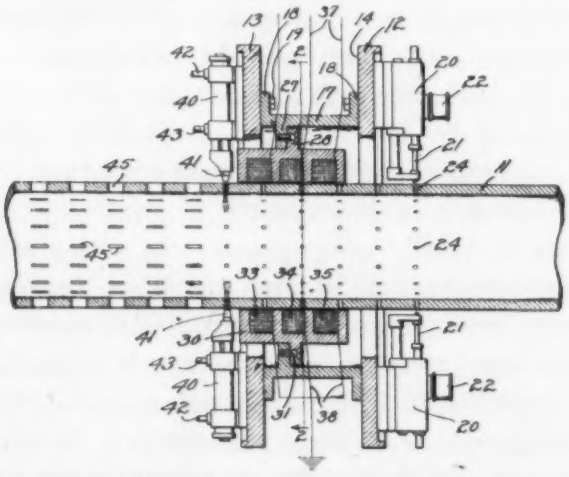
This concludes the discussion of annealing and all its better known variations based on a conception of stable structural conditions. In general in steel, an unstable structure is accompanied by high hardness, high strength and low ductility. A stable structure is accompanied by low hardness, relatively low strength and high ductility. In our discussion we have seen that complete stable equilibrium predicates a dissociation of cementite into iron and carbon but this is hardly ever possible in the steels. The most stable structural condition in the steels is coarsely laminated pearlite, divorced cementite or spheroidized cementite. As the structure of the steel gets finer, for example granular pearlite, it becomes more unstable, until we approach a condition of emulsified pearlite or even sorbite with little or no excess ferrite present. In hardened steels we will find other structural conditions still more unstable, namely troostite and martensite. These will be discussed in subsequent installments.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,666,166, Method of Cutting Slots in Metal, Clarence J. Coberly, of Los Angeles, California, Assignor to Kobe, Inc., of Los Angeles, California, a corporation of California.

This patent describes an apparatus and method for cutting slots in pipes for the formation of well strainers or the like, comprising an induction furnace 33, 34 and 35 which surrounds the pipe 11 to preheat the same and supports in advance of the movement of the furnace a plurality of radial



drills 21 adapted to drill holes 24 at desired points in the pipe wall and in the rear of the furnace a plurality of cutting torches 41 adapted to enlarge the holes 24 into slots as the apparatus moves along the pipes. By preheating the pipe by means of the induction furnace the cutting action of the torches 41 is greatly increased and the pipe is also left in a hardened condition.

1,666,312, Metallurgical Briquette and Process of Using It, William B. Runyan, of Dayton, Ohio.

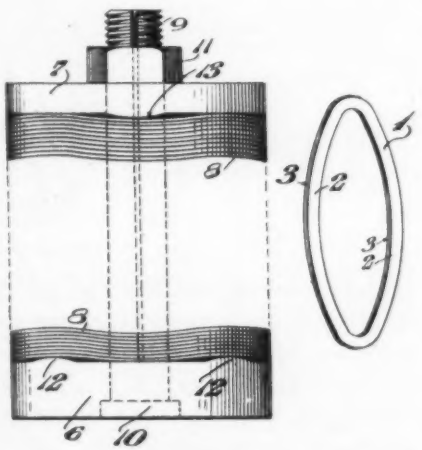
This patent describes a briquette for metallurgical purposes composed of a mixture of carbonaceous material, lime and sand to which may also be added spiegel iron or ferromanganese to act as a deoxidizer and give weight to the briquette. The briquettes may be added to the bath providing the necessary reducing agent together with the slag-making materials and may also be used to introduce manganese or carbon into the iron.

1,667,303, Flexible Metal Wall and Method of Making Same, Fred K. Bezzenberger, of Cleveland Heights, Ohio, Assignor, by mesne assignments to The Fulton Sylphon Company, of Knoxville, Tennessee, a corporation of Delaware.

This patent relates to a process of producing corrugated flexible metal walls or bellows of ferrous metal without the rolling and annealing operations now used in preparing metal bellows from brass or the like. According to the preferred process, a relatively pure iron, containing not over 0.10 per cent carbon, is formed in a complete fold or bellows by means of an internal fluid pressure in one or more drawing operations with intermediate annealing, if necessary. The formed bellows is then subjected to case hardening or carbonizing treatment to convert the same into steel.

1,668,297, Spring and Method of Making Same, William Wuerfel, of Philadelphia, Pennsylvania, Assignor to Wilkening Manufacturing Co., of Philadelphia, Pennsylvania, a corporation of Delaware.

This patent describes an apparatus and method of producing springs from cast iron, particularly piston rings which comprises placing a series of rings 1 under alternate forces caused by the projections 12 and 13 on the



disks 7 and 8 which are compressed upon the rings by means of the bolt 9 and nut 11 to cause wavy or helical formations around the rings 1. The rings when suitably distorted between the projections 12 and 13 are subjected to a sufficient temperature to cause the same to assume a permanent set and are then split to permit them to be spread over a piston or the like.

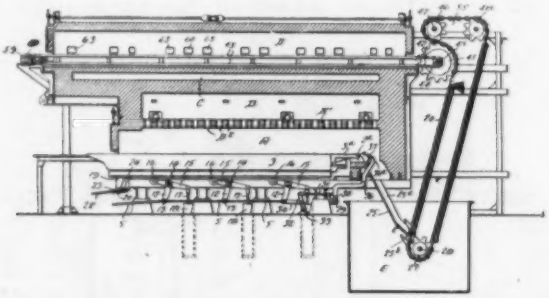
1,668,306, Refractory Material and Process of Producing the Same, Joseph G. Donaldson and Henry L. Coles, of Hamilton, Ohio, Assignors to Guardian Metals Company, of Hamilton, Ohio, a corporation of Delaware.

This patent describes a material for safe plates or the like adapted to resist attacks by the local application of high heat, such as the oxy-acetylene torch. Copper cannot be cut by oxidation because of its high heat conductivity, but it has a relatively low melting point. The present inventors have found a method of raising the melting point by the addition to copper of carbon from 0.015 to 0.020 per cent and silicon from 0.60 to 0.75 per cent. The copper is preferably heated to a molten condition in a direct-arc type of furnace from which sufficient carbon enters the copper

from the electrodes and when the metal has reached a high heat from 2 to 2½ per cent by weight of 30-per cent cupro-silicon in powdered form is added. The metal is stirred rapidly, and after thorough mixing can be cast in the usual way. This alloy has a higher melting point than copper alone, and will not flow when raised above this melting point, but appears to slowly slough off in small flakes.

1,668,164, Apparatus for Heating and Transfer of Articles, Harry P. McCann, of Cleveland, Ohio.

This patent describes a heat treating apparatus comprising the lower heat treatment chamber A, combustion chamber B, distributing chamber C and upper heat treatment chamber D. A quenching tank at the end of the lower heat treatment chamber is indicated at E. The articles to be



heated are placed in the chamber A and through movement of the walking beam 3, actuated by the rod 5, are given a step by step movement through the chamber A and at the end are received in the transfer mechanism, dropped one at a time into the chute 25 where they descend into the quenching solution E and are then elevated by means of a conveyor 26 and placed upon the conveyor 43 extending through the upper heat treatment chamber D.

1,667,476, Method of Increasing the Elasticity of Metal Articles, George L. Kelley, of Philadelphia, Pennsylvania, Assignor to Budd Wheel Company, of Philadelphia, Pennsylvania, a corporation of Pennsylvania.

This patent relates to a method of increasing the elasticity of metal articles and particularly steel locking rings commonly used on automotive vehicle wheels. The previous practice has been to cut these rings to the exact length to form the ends, coil the same into a ring and place in a hot pickling solution to remove scale and to impart tension. The action of the heated pickling solution is, however, not always reliable and the present invention proposes to pickle the bars prior to forming into a ring and after forming subject them to a heat of between 200 and 800 degrees Fahr. from ½ to 30 minutes. The desired temperature is 300 to 400 degrees Fahr. for a period of three to four minutes. This provides a more uniform article of the proper degree of elasticity.

THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each month with a specially prepared section of The Engineering Index. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the copy prepared for the annual volume of the Index published by the A. S. M. E.

In the preparation of the Index by the staff of the A. S. M. E. some 1,200 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders. A separate print is required for each page of the larger periodicals, but whenever possible two pages will be photographed together on the same print. When ordering prints, identify the article by quoting from the Index item: (1) Title of article; (2) name of periodical in which it appeared; (3) volume, number, and date of publication of periodical; and (4) page numbers.

AIRCRAFT ENGINES

MANUFACTURE—METALS. Material for Aircraft Parts Subjected to High Temperatures, J. B. Johnson. *Aeronautics (A. S. M. E. Trans.)*, vol. 50, no. 6, Jan.-Apr. 1928, 6 pp., 11 figs.

Operating conditions and materials used in engine parts; desirability of developing better materials to meet requirements of modern design; reference made to Liberty engine design; aircooled engine attains higher temperatures; temperatures attained in various parts; material for cylinder heads and pistons; aluminum alloys too soft for valve seats; tests to obtain better valves.

MANUFACTURE — METALS. Metallurgy of Aircraft Engines, B. Clements. *Aeronautics (A. S. M. E. Trans.)*, vol. 50, no. 6, Jan.-Apr. 1928, 2 pp.

Metals used in production of aircraft engine parts; their heat treatment and hardness attained; steels for connecting rods, crankshafts, and gears; bronzes and brasses; two principal bronzes used for valve seat inserts; aluminum and magnesium alloys; duralumin cannot be used in parts which require high tensile strength or high modulus of elasticity.

MANUFACTURE (WHIRLWIND). Whirlwind Engine Parts Require Many Operations, F. L. Faurote. *Iron Age*, vol. 121, no. 13, Mar. 29, 1928, pp. 867-870, 11 figs.

Production of crankcase, pistons, piston pins, valve springs, and crankshaft of Wright Whirlwind J-5 engine; care in molding crankcase; 85 operations needed to complete crankshaft; pistons seasoned by special heat treatment; broaching wristpin hole; pins quenched in vertical position to prevent warping; Wright valves purchased outside and checked by chemical and metallurgical tests in plant.

ALLOY STEELS

LOCOMOTIVE FORGINGS. Locomotive Forging Steels, O. V. Greene. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 4, Apr. 1928, pp. 573-588 and (discussion) 588-602, 18 figs.

Results of tests made on various types of heat treated alloy steels for reciprocating locomotive parts; many railroads are using normalized steel for their forgings; normalized forging steel tends to eliminate internal fissures and cracks, internal strains, ferritic segregation due to nonmetallic impurities; if weight is important factor, however, such steels as vanadium or manganese are used so that sections may be safely reduced in size.

TITANIUM CONTENT. The Influence of Titanium on Ternary Iron-Carbon-Nickel Steels (Der Einfluss von Titan auf ternaere Eisen-Kohlenstoff-Nickel-Staehle), R. Vogel. *Stahl u. Eisen (Duesseldorf)*, vol. 48. no. 13, Mar. 29, 1928, p. 410.

Discusses influence of titanium on pearlitic transformation of carbon steels in presence of other constituents, in this case, nickel. Abstract of Report No. 106, of Verein deutscher Eisenhuettenleute.

ALUMINUM

UTILIZATION—CHEMICAL APPARATUS. Use of Aluminum in Manufacture of Chemical Apparatus (Die Verwendung des Aluminiums im Apparatebau), H. Buschlinger. *Chemische Fabrik (Berlin)*, no. 3, Jan. 18, 1928, pp. 29-31.

General discussion of advantages of using aluminum in chemical manufacturing processes in which apparatus used must possess high resistance to acid corrosion and high heat conductivity.

Those members who are making a practice of clipping items for filing in their own filing system may obtain extra copies of the Engineering Index pages gratis by addressing their request to the society headquarters, whereby their names will be placed on a mailing list to receive extra copies regularly.

WELDING. Welding of Aluminum (Bemerkenswertes ueber die Aluminium-schweissverfahren und ihre technische Bedeutung), H. Holler. *Autogene Metallbearbeitung (Halle, Germany)*, vol. 21, no. 4 and 5, Feb. 15 and Mar. 1, 1928, pp. 46-54 and 66-70, 30 figs.

Description of methods used in welding aluminum plates, pipes, vessels, etc.; microstructure of aluminum welds; study of hammer welded joints of aluminum.

ALUMINUM ALLOYS

CADMIUM CONTENT. The Estimation of Cadmium in Aluminium Alloys, N. F. Budgen. *Metal Industry (Lond.)*, vol. 32, no. 12, Mar. 23, 1928, p. 297.

Observations recorded were outcome of attempt to obtain rapid and accurate method for their analysis.

CORROSION. Light Alloy Corrosion Testing, Rackwitz. *Metallurgist (Supp. to Engineer, Lond.)*, Mar. 30, 1928, pp. 46-47, 2 figs.

General statement on corrosion behavior of light aluminum alloys, more particularly duralumin, with account of extended investigation into methods of corrosion testing in German aircraft research establishment. Abstract translated from Korrosion und Metallschutz, Aug. 1927, p. 171.

HEAT TREATMENT. Heat Treatment of Aluminum and Its Light Alloys, R. J. Anderson. *Fuels and Furnaces*, vol. 6, no. 3, Mar. 1928, pp. 315-318, 2 figs.

Discussion of purpose of, and fundamental principles involved in, annealing, quench hardening, and aging of aluminum and aluminum-alloy products; annealing of wrought aluminum; theoretical considerations; mass annealing; continuous or so-called "flash" annealing.

ALUMINUM ALLOY CASTINGS

The Influence of Sodium on the Mechanical Properties of Aluminum Copper Alloys, W. Claus and F. Goederitz. *Foundry Trade Jl. (Lond.)*, vol. 38, no. 605, Mar. 22, 1928, pp. 204.

With exception of slight improvement of Brinell hardness, addition of sodium does not influence mechanical properties at all; micrographic inspection, however, revealed that this influence really exists in case of chilled samples; with sand-cast samples refining of grains was not perceptible but just under scale; experiments show that modification of aluminum alloys depends upon thermal conditions. Abstract translated from Giesserei, vol. 15, nos. 2 and 3, pp. 55 and 82.

ALUMINUM BRONZE

Aluminum Bronze. *Metallurgist (Supp. to Engineer, Lond.)*, Mar. 1928, pp. 42-43.

Self-annealing; influence of zinc, manganese, and pouring temperature; casting difficulties and remedies; wrought aluminum bronze; influence of lead; aluminum brasses. (Continuation of serial.)

AUTOMOBILES

BODIES, STEEL. Sheet Steel for Automobile Bodies. *Blast Furnace and Steel Plant*, vol. 16, no. 3, Mar. 1928, pp. 368-373. 2 figs.

Manufacture of sheet steels for automobile bodies; defects in ingots; influence of chemical composition; soaking pits and operation of soaking; influence of metallic elements; average chemical limits of heat; heating of ingots; scaling and burning; blooming mill; effect of ingot temperature on rolling. (To be continued.)

BODIES, STEEL. Heat Steel for Automobile Bodies. *Heat Treating and Forging*, vol. 14, no. 3, Mar. 1928, pp. 263-267.

Soaking pits; rolling blooms, slabs and sheet bar; gage variations and bar weights; chemical variations and physical condition of sheet; heating of ingots; scaling and burning; effect of ingot temperature on rolling; surface defects of bloom and sheet bar. (Concluded.)

CHASSIS — WELDING vs. RIVETING. Riveted or Welded Automobile Chassis Frames (Genietete oder geschweisste Kraftwagenrahmen), H. Splinder. *Motorwagen (Berlin)*, vol. 31, no. 6, Feb. 29, 1928, pp. 102-105, 6 figs.

Reports tests by author on relative strength of welded and riveted joints of channel beams; results indicate superiority of welded joints.

AUTOMOBILE ENGINES

CONNECTING RODS—MACHINING. Precision Required in Machining of Lincoln Connecting Rods, K. W. Stillman. *Automotive Industries*, vol. 58, no. 14, Apr. 7, 1928, pp. 558-559, 7 figs.

Very small tolerances permitted; operations carried out on forked rods for V-type engine; locating surfaces milled; holes in both ends of rods drilled and reamed; joint face ground; final reaming and grinding operations performed just before rods are assembled with pistons.

PISTON RINGS—GRINDING. Auto Piston Ring Production on a Quantity Basis. *Abrasive Industry*, vol. 9, no. 4, Apr. 1928, pp. 107-108, 4 figs.

Piston ring manufacture is branch of machine work calling for utmost precision on parts made in enormous quantities; methods at plant of General Piston Ring Co.; outside snagging; insides of piston rings rough ground; final sizing for thickness on automatic surface grinding machine; insides of piston rings ground on internal grinding machines.

BEARING METALS

Lubrication and Bearing Metal Problems in Metallurgical Works (Schmiermittel-und Lagermetallfragen im Huettenbetriebe), K. Hopfer. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 13, Mar. 29, 1928, pp. 408-410, 2 figs.

Refers to early and more recent works on development of hydrodynamic bearing friction theory, and discusses properties and suitability of different bearing alloys; claims that problem of bearing metal and lubricant cannot be treated separately.

BEARING METALS, BRONZE

Characteristics of Bronze Bearings. *Am. Mach.*, vol. 68, no. 15, Apr. 12, 1928, p. 627.

Control of mixture of bearing bronze important; lead sometimes used but does not combine chemically with copper; zinc alloys, or brasses, do not make good bearings; bronze containing 80 per cent copper and 20

per cent tin, deoxidized with phosphorus, is recommended for heavy-duty bearings.

BEARINGS

BABBITTING. Rebabbitting Bearings. *Power Plant Eng.*, vol. 32, no. 7, Apr. 1, 1928, pp. 413-414, 5 figs.

Statement of practical considerations necessary to secure success in babbitting; table of physical characteristics of different compositions of white bearing metals.

BEARINGS, BALL

MANUFACTURE. The Manufacture of Ball and Roller Bearings, G. James. *Iron and Steel of Can.*, vol. 11, no. 2, Feb. 1928, pp. 37-44, 22 figs.

Outline of major operations in manufacture; types of ball and roller bearings; initial forming methods of steel balls; furnace for hardening; rough hard grinding or lapping; final grinding; polishing and surface inspection; gaging; forming; annealing and machining bearing rings. Paper read before Montreal Branch of Eng. Inst. of Can.

BEARINGS, ROLLER

MANUFACTURE. The Manufacture of Ball and Roller Bearing, G. James. *Iron and Steel of Can.*, vol. 11, no. 2, Feb. 1928, pp. 37-44, 22 figs.

Outline of major operations in manufacture; types of ball and roller bearings; initial forming methods of steel balls; furnace for hardening; rough hard grinding or lapping; final grinding; polishing and surface inspection; gaging; forming, annealing and machining bearing rings. Paper read before Montreal Branch of Eng. Inst. of Can.

BOILER PLATE

NICKEL STEEL. Alloy Steel for Boiler Construction, C. McKnight. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 4, Apr. 1928, pp. 638-657 and (discussion) 657-658, 10 figs.

As material for boiler construction nickel steel offers following advantages: it is between 25 and 40 per cent stronger than carbon steel with practically same toughness and greater resistance to impact; at boiler temperatures it is much superior to carbon steel; it is immune to aging embrittlement; it can be made to develop even higher strengths than are now demanded; it is resistant to boiler corrosion; it is suited for use as boiler tubes and staybolts. Bibliography.

BRASS CASTING

The Casting of Brass Strip, N. F. Fletcher. *Junior Instn. Engrs.—Jl. (Lond.)*, vol. 38, part 5, Feb. 1928, pp. 218-237, 8 figs.

Melting and casting of brass is most important stage in its manufacture, since faults created here cannot be eradicated by subsequent working; raw material; crucibles tested for soundness; electric furnaces; mold dressings; inclination of molds to vertical; thickness of ingots; pouring temperature; loss of metal during melting and casting of brass.

Producing Sound Brass Castings, R. R. Clarke. *Brass World*, vol. 24, no. 3, Mar. 1928, pp. 78-79.

Practical discussion of problem that confronted operators of fairly large general jobbing foundry; iron best added to molten copper by saturation or dissolution; adding roll sulphur; dross and wormy appearance on cope side of flange come from poor grades of metal, especially zinc, too wet sand, cold metal, loose gating practice; aluminum lowers brazing properties of metal.

BRASS INGOTS

SOUNDNESS. The Influence of Dissolved Gases on the Soundness of 70:30 Brass Ingots, G. L. Bailey. *Engineering (Lond.)*, vol. 125, no. 3245, Mar. 23, 1928, pp. 366-368, 5 figs.

Investigation to determine how far soundness of brass ingots might be affected by treating liquid brass with various gases before casting. Abstract of paper read before Inst. of Metals.

BRICK, MAGNESITE

Properties of Magnesite Bricks (Die Eigenschaften der Magnesitsteine), H. Hirsch. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 12, Mar. 22, 1928, pp. 371-372.

Abstract of Report, No. 117, of Werkstoffausschuss des Vereins deutscher Eisenhuettenleute, published in Archiv fuer das Eisenhuettenwesen, Dec. 1927, p. 439.

Properties of Magnesite Bricks (Die Eigenschaften der Magnesitsteine), H. Hirsch. *Tonindustrie-Zeitung (Berlin)*, vol. 52, no. 25, Mar. 24, 1928, pp. 479-483, 14 figs. partly on supp. plate.

Work was first published in Archiv fuer das Eisenhuettenwesen, 1927, p. 439

Silica and Magnesite Bricks in Metallurgical Furnaces, F. Wolff. *Metal Industry (Lond.)*, vol. 32, no. 7, Feb. 17, 1928, pp. 177-178 and 183.

Points out characteristic advantages and disadvantages of silica and magnesite bricks and their limits of usefulness for metallurgical purposes. (To be continued.)

BRICK, SILICA

PROPERTIES. Silica Bricks for Steel Foundries, A. H. Middleton and C. Bride. *Iron and Steel of Can. (Gardenvale, Que.)*, vol. 11, no. 3, Mar. 1928, pp. 77-79.

Ideal refractory should possess high refractories, great mechanical strength at all temperatures, resistance to spalling on sudden heating, anti-slagging properties, resistance to abrasion by furnace gases, and minimum thermal expansion; good silica brick represents useful compromise of these qualities; accuracy of size depends mainly on control of kiln firing. Abstract of paper read before West of Scotland Iron and Steel Inst.

Silica and Magnesite Bricks in Metallurgical Furnaces, F. Wolff. *Metal Industry (Lond.)*, vol. 32, no. 7, Feb. 17, 1928, pp. 177-178 and 183.

Points out characteristic advantages and disadvantages of silica and magnesite bricks and their limits of usefulness for metallurgical purposes. (To be continued.)

Silica and Magnesite Bricks in Metallurgical Furnaces, G. Wolff. *Metal Industry (Lond.)*, vol. 32, no. 9, Mar. 2, 1928, pp. 236-237.

Judging source of difficulties; care of magnesite brick linings; chemical action on furnace linings. (Concluded.)

RAW MATERIALS. Why Quartzite Sandstone is Preferable as a Raw Material for the Manufacture of Silica Bricks (Worauf

beruht die Ueberlegenheit der Quarzitsandsteine als Material zur Herstellung von Quarzziegeln), P. J. Holmquist. *Ingenioers Vetenskaps Akademien—Handlingar (Stockholm)*, no. 64, 1927, 18 pp., 5 figs.

Investigation of effect of burning crystalline quartzites and quartzite sandstones, difference in swelling coefficient and in quartz transformations caused by heat; gas content of quartz minerals and its effect on transformations in silica bricks. (In German.)

BRONZE FOUNDRIES

METAL RECOVERY. Metal Recovery from Bronze Foundry Slags, E. R. Darby. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 113, Apr. 1928, 3 pp.

Metallic oxide in slag usually so diluted that recovery is economically impossible; fine particles of free metal also carried away; tests and practice at foundry where net saving from slag exceeded $13,000 in one year, after deducting cost of special furnace; average tin content of metal saved was about 20 per cent, while content of foundry product was only 6.25 per cent.

BRONZE GEAR

Developments in Gear Bronze, T. H. W. Jeacock. *Can. Foundryman (Toronto)*, vol. 19, no. 3, Mar. 1928. pp. 30-31.

Best bronze worm-gear blanks made with nickel content by process known as three-sided chill; inclusion of nickel in bronze alloy for gear blanks increases yield point considerably with but slight loss in elongation; outstanding advantages gained by inclusion of nickel are decreased pitting of wheel-teeth surface, increased wearing quality, lower operating temperatures.

CADMIUM

Cadmium and Its Uses (Le cadmium et ses applications), M. Cournot. *Société des Ingenieurs Civils de France—Memoires*, vol. 80, nos. 9-10, Sept.-Oct. 1927, pp. 1081-1114, 15 figs.

Origin, methods of extraction, deposits, properties and use of metal and its alloys with other metals; applications in industry and methods of electroplating.

CADMIUM—UTILIZATION

ELECTRIC INDUSTRY. The Applications of Cadmium, N. F. Budgen. *Elec. Rev. (Lond.)*, vol. 102, no. 2623, Mar. 2, 1928, pp. 366-368.

Outline of several important applications of cadmium in electrical industry; electric batteries; cadmium lamps; cadmium-oxide electric-furnace resistors; cadmium vapor-arc lamp; cadmium-copper wire for telegraph, telephone, and power transmission.

CARTRIDGE CASES

HEAT TREATMENT. Heat Treatment of Cartridge Cases in an Electric Furnace (Glodgning av patronhylsammen i elektrisk ugn), O. Stalhane and B. Stalhane. *Ingeniors Vetenskaps Akademien—Meddelande (Stockholm)*, no. 79, 1928, 26 pp., 14 figs.

Report on course of heating and temperature giving best results; description of experimental furnace; oxidation, polish, quality of metal, determination of hardness and malleability; construction of new furnace for manufacturing purposes.

CAST IRON

COMPOSITION. The Structural Composition of Cast Iron by Weight and Volume, W. E. Dennison. *Foundry Trade Jl. (Lond.)*, vol. 38, no. 606, Mar. 29, 1928, pp. 224-225 and 230, 1 fig.

Method of selectively apportioning elements as given by ultimate analysis; how elements exist; procedure of computation; volumetric considerations; structural diagrams.

DEVELOPMENTS. Recent Developments in Cast Iron, J. G. Pearce. *Metallurgist (Supp. to Engineer, Lond.)*, Mar. 1928, pp. 39-42, 6 figs.

Presents test figures, and photomicrographs obtained in Cast Iron Research Association's laboratory on actual samples furnished by makers; hot-mold process; low-carbon iron; chilled irons. (Continuation of serial.)

NICKEL ADDITIONS. Improving Cast Iron by the Addition of Nickel or Nickel and Chromium. *West. Machy. World*, vol. 19, no. 3, Mar. 1928, p. 127.

Result of experiments; question of increased strength; securing of greater toughness; uniformly increased harness with better machinability; considerably increased wear resistance; problem of adding nickel to iron.

PROPERTIES. Mechanical and Physical Properties of High-Grade Gray Cast Iron and Principles Underlying Its Production (Hochwertiger Grauguss, seine mechanisch-physikalischen Eigenschaften und die Grundlagen zu seiner Erzeugung), E. Zimmermann. *Zeit. fuer die gesamte Giessereipraxis (Berlin)*, vol. 49, nos. 11 and 12, Mar. 11 and 18, 1928, pp. 104-105 and 111-112.

Mar. 11: Graphite eutectoid. Mar. 18: Cast iron according to Thyssen-Emmel process. (Continuation of serial.)

PROPERTIES. High-Grade Cast Iron, J. E. Hurst. *Foundry Trade Jl. (Lond.)*, vol. 38, no. 606, Mar. 29, 1928, pp. 226-228, 1 fig.

Deals with properties of cast iron, namely, soundness, machinability, ultimate strength, resistance to impact, resistance to wear and resistance to volume changes and distortion under heat influence; cast iron for high-duty conditions should contain lowest silicon content and total carbon contents, and highest combined carbon contents compatible with commercial machinability and soundness of castings.

SULPHUR DETERMINATION. The Predetermination of the Sulphur Content of Cast Iron in Cupola Operation (Die Vorausbestimmung des Schwefelgehaltes im Gusseisen beim Kupolofenbetrieb), B. Osann. *Giesserei (Duesseldorf)*, vol. 15, no. 9, Mar. 2, 1928, pp. 204-206.

Presents table showing empirical method of calculating burden; and table giving predetermination of sulphur content in cupola melting, according to method developed by author.

TEST BARS. The Test-Bar Problem and Some Recent Developments, J. G. Pearce. *Foundry Trade Jl. (Lond.)*, vol. 38, no. 605, Mar. 22, 1928, pp. 201-203, 1 fig.

Refers to recommendations embodied in new specifications about to be issued by British Eng. Standards Assn.; shows why standard bar should be cylindrical; cast-on versus cast-off test bars; tensile and transverse test; modulus of rupture; shear and

Brinell test; relations between tests; advantages of standard bar become apparent on accumulating routine results.

TEST BARS. Conversion Factors for Round Test Bars, W. Kuebler and W. C. Murray. *Foundry*, vol. 56, no. 6, Mar. 15, 1928, supp. sheet.

Due to molding conditions, diameter of test bar will vary, table prepared for use in foundry testing laboratory; calculations are based on new tentative revision of Am. Soc. Testing Materials' standard bar.

TEST BARS. Tests for Cast Iron and Test Bar Problem. *Foundry Trade Jl. (Lond.)*, vol. 38, no. 606, Mar. 29, 1928, p. 228.

Discussion of paper by J. G. Pearce, published in Mar. 22 issue of this journal.

CAST IRON, ACID RESISTING

High-Silicon Cast Iron or Acid-Resisting Iron, E. Whitaker. *Foundry Trade Jl. (Lond.)*, vol. 38, no. 604, Mar. 15, 1928, pp. 189-190, including discussion.

Phosphorus content must be restricted to about 0.2 per cent, sulphur about 0.05, manganese 0.3 per cent, while the best work has been done with silicon at 13 to 15 per cent; factors influencing success. Abstract.

CHROMIUM PLATING

Warns Against Quickly Applied Chromium Plating. *Iron Age*, vol. 121, no. 14, Apr. 5, 1928, p. 940.

Slight variations of chemicals in solutions or any other factor relating to deposition create distinct variations in properties of plate; rule of thumb inadequate; from 10 minutes to 20 hours required to make satisfactory surface depending upon expected duty and character of underlying metal; thickness of decorative coatings. Abstract of paper presented before Am. Soc. Mech. Engrs.

Chromium Plating Is Discussed, E. G. Lovernug. *Abrasive Industry*, vol. 9, no. 4, Apr. 1928, pp. 108-110.

Situation developed from growing use of chromium as electroplated coating for metals; difficulties from misleading publicity; firms holding back from installing chromium equipment for fear of litigation; demand for chromium-plated parts heard everywhere; lack of information; chromium plating on automobile lamps, using process worked out to fit class of work.

Chromium Plating, C. H. Proctor. *Brass World*, vol. 24, no. 3, Mar. 1928, pp. 85-86.

Qualities of chromium deposits, and different fields to which they can be applied; properties of chromium plate; working of chromium baths; current density used; imperative to provide for effective exhaust hood; rustproof coatings; method of heating steel parts which have to be made perfectly rustproof. Translation of paper by A. Butziger, read before Am. Electroplaters' Soc.

COPPER

DEVELOPMENTS. Copper and Copper Alloys, S. H. Bassett. *Min. and Met.*, vol. 9, no. 256, Apr. 1928, pp. 170-174, 2 figs.

Emphasizes American influence in modern copper smelting and refining; electrolytic refinery methods well under control; brass most important alloy of copper; enumerates outstanding accomplishments, particularly alloys containing more than small fraction of per cent of silicon; uses of copper and its alloys increased within past decade, partly due to advertising.

COPPER ALLOYS

Useful Copper Alloys, Old and New, W. H. Bassett. *Iron Age*, vol. 121, no. 15, Apr. 12, 1928, pp. 1009-1010.

High-copper brasses needed to resist corrosion cracking; copper hardened with silicon and manganese or nickel has strength of mild steel; copper-nickel alloys favored for quality hardware; rolled and drawn copper require rigid control of ingot metal; high copper alloys do not season-crack or dezincify; various forms of hardened copper.

DIE CASTING MACHINES

Die Casting Machine for Trial Parts, H. L. Thompson. *Machy. (N. Y.)*, vol. 34, no. 7, Mar. 1928, pp. 521-526, 6 figs.

Rapid-acting single-cavity die casting machine described; burner for melting metal; pump forcing metal into die; die for producing part with thread; method of holding die shut; metal-tight connection between die and pump; extracting work; cooling die; supporting and locating die on machine; ejector; melting temperature of metals; interlocking cores; pump plunger; keeping metal in proper condition; chute for conducting castings from machine; finishing castings.

ELECTRIC FURNACES (Tammann)

Recent Progress in Construction of Electric Furnaces After Tammann (Die neuere Entwicklung der elektrischen Hochtemperaturoefen nach Tammann), E. Loewenstein. *Chemische Fabrik (Berlin)*, no. 7, Feb. 15, 1928, pp. 77-78, 6 figs.

Describes practical types of Tammann furnaces, formerly used only in laboratories, now made in sizes up to 150 kg. capacity and used for melting of metals, alloys glass, ores, enamel, etc.

ELECTRIC FURNACES, CARBURIZING

Large Carburizing Furnace Secures Recuperative Economies, W. J. Diedrichs. *Elec. World*, vol. 91, no. 13, Mar. 31, 1928, pp. 667-668, 1 fig.

Single-end box-type furnace and recuperating chamber, both of special design, have been combined as unit for carburizing and normalizing of machine-tool parts with notable operating economies; furnace has electrical input of 81 kw. for operation on 220-volt 3-phase power supply.

ELECTRIC FURNACES, HEAT TREATING

Heat Treatment in Electrical Furnaces. *Metal Industry (Lond.)*, vol. 32, no. 13, Mar. 30, 1928, pp. 330-331, 1 fig.

Advantages claimed in use of electric furnaces for annealing and heat treatment of metals; question of costs; recuperative-type resistance furnace; heating elements and control.

ELECTRIC FURNACES, IRON FOUNDING

Electric Furnace Iron. *Iron Age*, vol. 121, no. 14, Apr. 5, 1928, p. 955.

Results of extended experiments show prac-

ticability, advantages and costs; electric furnace used in conjunction with cupola; possibility of producing electric furnace cast iron from cheap grades of ferrous scrap; one electric furnace can be used to produce both iron and steel; electric iron stronger.

Electric-Furnace Cast Iron, C. E. Williams and C. E. Sims. *U. S. Bur. Mines—Tech. Paper,* no. 418, 1928, 48 pp., 10 figs.

Production of cast iron in electric furnace; strength; fine-grained condition; desulphurization; superheating; duplexing; present uses and supply of ferrous scrap; study of carburization; production of synthetic cast iron in electric furnace and in cupola; type of scrap melted in electric furnace; summary of investigation and cost of producing iron.

ELECTRIC FURNACES, ROTARY HEARTH

Rotary-Hearth Furnace for Small Pieces, W. J. Diederichs. *Elec. World,* vol. 91, no. 15, Apr. 14, 1928, p. 766, 1 fig.

Automatic discharging device, incorporated in electric furnace of rotary-hearth type, permits hardening of cap screws and similar parts with satisfactory operating economies.

ELECTRIC HEATING

Principles Involved in Electric Heating, N. R. Stansel. *Heat Treating and Forging,* vol. 14, no. 3, Mar. 1928, pp. 311-314, 7 figs.

Apparatus and methods used in converting electricity into heat; principles of heat transfer, conduction, convection and radiation; transfer and absorption of heat; standard surface for heat radiation is black-body condition.

FURNACES, HEAT TREATING

Forging and Heat Treating of Long Cylinders, J. B. Nealey. *Iron Age,* vol. 121, no. 14, Apr. 5, 1928, p. 942, 2 figs.

Special equipment installed at Miehle Printing Press & Mfg. Co.; vertical furnace to case-harden rollers and shafts; parts lowered into vertical retorts charged with small amount of carbonizing material; three-high furnace; upper chamber gets first impact of gas flame, and waste heat from it is passed down into other two; two helve hammers are used for swaging ends on press rollers.

AUTOMATIC CONTROL. Spring Heat Treating Furnaces Automatically Controlled, F. Stones. *Fuels and Furnaces,* vol. 6, no. 3, Mar. 1928, pp. 373-376, 6 figs.

Automobile spring heat treating unit consists of hardening and tempering furnaces which are fired with oil and have temperatures automatically controlled; cambering and hardening furnace of continuous type; hardening furnace of over-fired type; tempering furnace; tempering furnace of continuous type; each furnace is equipped with two controlling pyrometers and valves.

FURNACES, INDUSTRIAL

DESIGN. Industrial Furnaces, V. J. Azbe. *Mech. World. (Manchester, Eng.),* vol. 83, no. 2151, Mar. 23, 1928, pp. 215-216, 6 figs.

Importance of relative temperature and temperature differential in comparison of efficiencies of industrial and boiler furnaces; in high-temperature work, oxygen is less desirable; use of oil burners, coal stokers, and gas producers, and their influence upon final efficiency. From paper presented to Am. Soc. Mech. Engrs.

FURNACES, METALLURGICAL

GAS AND OIL FIRING. New Gas-Fired and Oil-Fired Furnaces, J. Fallon. *Foundry Trade Jl. (Lond.),* vol. 38, no. 604, Mar. 15, 1928, pp. 181-182, 5 figs.

Particulars of several new types of gas-fired and oil-fired furnaces designed for specific service; tabular data on comparative heat content of coal, coke, oil, town gas and electricity.

EXHIBITION—ENGLAND. British Industries Fair. *Metal Industry (Lond.),* vol. 32, no. 9, Mar. 2, 1928, pp. 229-230 and 232, 2 figs.

Review of exhibits, including furnaces for heat treatment of metals; oil-fuel furnace for metal melting; gas furnaces; metal exhibits.

GEARS AND GEARING

MATERIALS. Materials of Construction and Heat Treatment on Highly Stressed Gears (Werkstoffe und Warmbehandlung hoch beanspruchter Zahnraeder), A. Hofmann. *V. D. I. Zeit. (Berlin),* vol. 72, no. 8, Feb. 25, 1928, pp. 259-264, 21 figs.

Fundamental differences in use and heat treatment of case-hardened and special, high-grade steels; German and American practice as to materials, heat-treatment processes (particularly case-hardening), methods of preventing hardening distortions, etc.

GRINDING WHEELS

Artificial Grindstones, Anti-Friction Bearings and Vacuum Thickener Developments, W. E. Brawn. *Paper Trade Jl.,* vol. 86, no. 8, Feb. 23, 1928, pp. 191 and 193.

Describes experiences with use of artificial stones which is probably more or less representative of early experience of most companies that have used them.

HEAT THEORY

On the Theory of Heat, H. Le Chatelier. *Am. Soc. Steel Treating—Trans.,* vol. 13, no. 4, Apr. 1928, pp. 555-572 and 602, 8 figs.

Author covers problems of suitable heating; supplying simultaneously of required amount of heat and temperature necessary for carrying out contemplated action; different types of perfected apparatus are explained, particularly shaft furnace, with its current gases, and burning of quartz; importance of even distribution of temperature within furnace and its necessary limitation as applied to melting cupola.

HEAT TREATMENT

FURNACE CONTROL. The Importance of Furnace Control for Heat Treatment of Nonferrous Metals, J. Silberstein. *Fuels and Furnaces,* vol. 6, no. 3, Mar. 1928, pp. 333-334, 1 fig.

Discussion of furnace control; hardening to secure increased strength requires close temperature regulation; annealing of copper; annealing of nickel and monel metal; hardening of nonferrous metals; increased strength of nonferrous alloys; mechanism of hardening.

HIGH SPEED STEEL

On the Double Carbide of High Speed Steel, A. Westgren and G. Phragmen. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 4, Apr. 1928, pp. 539-552 and (discussion) 552-554, 4 figs.

By means of X-ray analysis authors have proved identity of high-speed steel carbide with octahedral crystals grown in blowholes of ferrotungsten; Laue and rotation photograms have shown that crystal lattice of this phase is face-centered cubic; its elementary cube is probably occupied by 112 atoms; X-ray photograms of Fe-Mo-C alloys have proved existence of iron-molybdenum carbide analogous to that of iron-tungsten carbide of high-speed steel.

CUTTING. Tests in Machining Manganese Steel, A. S. Martin. *Heat Treating and Forging*, vol. 14, no. 3, Mar. 1928, pp. 282 and 296.

High-speed tool steel has been found effective in machining material hitherto practically unmachinable; other applications suggested; cutting operations; with tools made of steel under test, manganese steel can be commercially machined using cutting speeds from 7 1/2 to 15 ft. per minute with depths of cuts up to 5/32 in. and feeds of 1/60 in. to 1/50 inch.

IMPACT TESTING, NOTCHED BAR

The Significance of the Notched Bar Impact Test, W. Schwinning and K. Mattaes. *Metallurgist (Supp. to Engineer, Lond.)*, Mar. 30, 1928, pp. 47-48.

Notched-bar test is considered from standpoint of extent to which it can be employed to supplement ordinary tensile test, in order to determine mechanical properties of material; various types of fracture and how they arise. Review of booklet no. 78 of Deutsche Verband fuer die Materialpruefung der Technik.

INGOT STEEL

POURING SPEED. Influence of Pouring Speed on the Soundness of Steel Ingots. *Iron and Steel World*, vol. 2, no. 3, Mar. 1928, pp. 141-142.

Factors influencing rate of flow; factors which mainly influence rate of pouring are: viscosity of steel; pressure of metal in ladle; cross-sectional area of mold; number of ingots fed from one central runner, in bottom cast steel; size of nozzle in ladle; data on pouring ingots from 60-ton acid open-hearth furnace. Translated from Stahl u. Eisen.

INSPECTION METHODS

Inspection Methods, E. J. Parish *Mech. World (Manchester, Eng.)*, vol. 83, nos. 2150 and 2152, Mar. 16 and 30, 1928, pp. 203-204 and 239-241.

Mar. 16: Methods of checking article to compare with requirements of specifications; control by each individual department or by centralized inspection authority; concentrating standards, instruments, measuring machines, and gages in central department. Mar. 30: Raw-material inspection; inspection during manufacture; heat-treatment tests; final inspection; tool inspection; vernier slide, optical and screw gages; paper read before Manchester Assn. Engrs.

IRON, ELECTROLYTIC

Electrolytic Iron: Its Inception and Development. *Engineering (Lond.)*, vol. 125, no. 3245, Mar. 23, 1928, pp. 339-340, 6 figs.

Historical review; important factor in electrodeposition of iron is running of mandrel or cathode at minimum speed; Cowper-Coles was first to point out this fact; chief feature of Cowper-Coles process consists of cathode rotating at critical speed; coarse electrolytic iron, in unfinished state, contains very small proportion of impurities, such as silicon, phosphorus, sulphur, manganese and carbon; mechanical properties of electrolytic iron.

IRON ALLOYS

EQUILIBRIUM. Equilibria at High Temperatures in the System Iron-Oxygen-Carbon, R. R. Garran. *Faraday Soc.—Trans. (Lond.)*, vol. 24, no. 82, Mar. 1928, pp. 201-207, 2 figs.

System has been examined by calculation and by experiment; former method has been shown to be unreliable; experimental results are given in temperature range 600 to 1300 degrees Cent.

IRON AND STEEL

CORROSION. Corrosion of Iron and Steel, W. B. Lewis and G. S. Irving. *Machy. Market (Lond.)*, no. 1427, Mar. 9, 1928, pp. 217-218.

Old theories of corrosion compared with modern theory, and with special reference to marine boilers; acid and other theories; differential-aeration corrosion and application; two main types of corrosion; water-level corrosion; factors which influence corrosion; prevention; keeping boilers free from scale. Abstract of paper read before Inst. Mar. Engineers.

IRON AND STEEL INDUSTRY

Smaller Use of Pig Iron in Open-Hearth Furnaces. *Iron Age*, vol. 121, no. 15, Apr. 12, 1928, 1008, 1 fig.

Calculations of proportion of pig iron and of scrap used in open-hearth charges in first quarter of 1928; charge proportioning as affected by price ratio between iron and scrap shows close watching of markets; total scrap consumption; characteristics of first quarter-years.

IRON AND STEEL PLANTS

FUEL ECONOMY. Possibilities of Fuel Economy, H. A. Brassert. *Iron and Steel of Can.*, vol. 11, no. 2, Feb. 1928, pp. 44-46.

Opportunity for substantial fuel savings existing at most iron and steel plants; recent improvements in use of fuel; heat economy at German plants; proper application of blast-furnace and coke-oven gas; economic value of blast-furnace gas; economics of blast furnace as gas producer; enriching blast-furnace gas in producers of water gas generators. Abstract of paper read before Eastern States Blast Furnace and Coke Oven Assn.

IRON CASTINGS

TEST COLUMNS. Making a Test-column Casting, F. C. Edwards. *Foundry Trade Jl. (Lond.)*, vol. 38, no. 606, Mar. 29, 1928, pp. 219-220, 5 figs.

Describes example made in green sand, 10 ft. long, 3 ft. square, and weighing about 4

tons; plain, "boxed-up" block constituted pattern; special feature of pattern was entire absence of core prints; sequence of molding operations; pouring casting.

IRON ORE, CHROMIUM

ANALYSIS. Analysis of Chrome Iron Ore (Zur analytischen Untersuchung des Chromeisensteins), E. Dittler, *Zeit. fuer angewandte Chemie (Leipzig)*, vol. 41, no. 5, Feb. 4, 1928, pp. 132-133.

Author claims that fusion of this ore with sodium carbonate is never complete and describes manner in which analysis is best carried out. See brief translated abstract in Chem. and Industry (Lond.), vol. 47, no. 11, Mar. 16, 1928, p. 195.

LEAD

CORROSION. Apparent Spontaneous Disintegration and Corrosion of Lead, M. V. Schwartz. *Metal Industry (Lond.)*, vol. 32, no. 12, Mar. 23, 1928, p. 299.

Account of instances of phenomena in lead pneumatic piping, sheet-lead coverings of electromagnet coils and sheet lead formed into tubes for X-ray measuring instruments; author thinks that intercrystalline brittleness should be given its true perspective as mere result of recrystallization. Brief abstract translated from Korrosion und Metallschutz, Jan. 1, 1928.

LEAD ALLOYS

ALLOTROPY. Allotropic Changes in Tin and Lead Alloys, Travers and Houst. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 24, 1928, pp. 30-32, 5 figs.

In alloys used in printing industry containing tin, lead and antimony, changes occur even at ordinary temperature; immediately after casting, alloys are harder and less dense than they are after remaining at room temperature for some time. Abstract translated from Revue de Métallurgie, Sept. 1927.

HARDNESS TESTING. Some Peculiar Results in Hardness Tests of Lead-antimony Alloys, L. O. Howard. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 90, Mar. 1928, 5 pp., 2 figs.

Tests made at University of Idaho on series of chill-cast antimony-lead alloys show decided drop in hardness of alloys in vicinity of 50 per cent antimony; similar drop appears at 40 per cent antimony in similar series tested at South Dakota School of Mines; discrepancies in hardness numbers reported by various authors are doubtless due to different treatment given, as indicated by curves showing difference of quenched and aged specimens.

LOCOMOTIVE—FIREBOXES

FAILURES. Firebox Plate Failures, F. H. Williams. *Ry. Mech. Engr.*, vol. 102, no. 3, Mar. 1928. pp. 132-136, 13 figs.

Theory advanced that use of air hammers on plates sets up metal strains that permit corrosion; shows inside nature of failure in combination with outside features and points out that, while weld helped at start of fracture, real cause for final fracture was corrosive action of impure water on strained metal between staybolt holes; air hammers, used in fabrication of firebox, are cause of these strains in metal and subsequent corrosion pitting.

MALLEABLE CASTINGS

PROPERTIES. The Black Heart of Malleable Iron, O. Quadrat and J. Koritta. *Foundry Trade Jl. (Lond.)*, vol. 38, no. 604, Mar. 15, 1928, pp. 191-192, 1 fig.

Results of experiments with malleable iron in order to determine mechanical properties of black heart and to find out best method of heat treatment; properties of black heart at different temperatures; influence of cooling rate. Translated from Giesserei, nos. 49 and 50, Dec. 3 and 10, 1927, pp. 849 and 865.

MALLEABLE IRON

MANUFACTURE. Manufacture of Malleable Iron, A. E. White. *Can. Foundryman (Toronto)*, vol. 19, no. 3, Mar. 1928, pp. 11-14, 20 figs.

Composition, physical properties and structural constituents; time required to produce equilibrium in iron-carbon alloys used in making malleable cast iron varies from 4 hours at 1800 deg. fahr. with high-silicon alloys to 275 hours at 1400 deg. fahr. for medium-silicon alloys and longer for low-silicon alloys; combined carbon for equilibrium conditions; maximum cooling rate compatible with successive maintenance of equilibrium found.

STANDARDIZATION. Revised Recommendations for the Standardization of Malleable Iron (Geaenderte Vorschlaege fuer die Normung von Temperguss), R. Stotz. *Giesserei (Duesseldorf)*, vol. 15, no. 11, Mar. 16, 1928, pp. 248-249.

Gives revised recommendations of German Industrial Standards Committee based on suggestions submitted by Association of German Malleable Iron Foundrymen; minimum values for tensile strength and elongation of high-grade white-heart and black-heart malleable are given.

MANGANESE STEEL

Low-Manganese Steel Gains Favor, J. Strauss. *Iron Age*, vol. 121, no. 13, Mar. 29, 1928, pp. 864-866, 5 figs.

Low-manganese steels may be heat treated to properties comparable with more expensive alloy steels and are finding increasing application; critical points displaced so air hardening may result; properties of heat-treated 1-in. bars; overheating not especially damaging; temper brittleness depends on method of manufacture; hardening of larger sections; machining qualities. Abstract of paper read before Am. Soc. for Steel Treating.

PROPERTIES. The Properties of Manganese Steel, J. H. Hall. *Can. Ry. Club—Proc. (Montreal)*, vol. 27, no. 1, Jan. 1928, pp. 20-30 and (discussion) 31-34, 2 figs.

Manganese steel has remarkable but not unique combination of strength and toughness; its unique property is its hardness and hardening power; chemical composition and ordinary physical properties of heat treated manganese steel in cast condition; makes manganese steel by mixing in ladle melted Bessemer blown metal and melted 80-per cent ferromanganese; 3-ton basic-lined Heroult electric furnace is also used.

MATERIALS, TESTING

STRESS DETERMINATION. An Optical Method of Determining Internal Stresses in Homogeneous Materials, C. F. Ffolliott.

Rensselaer Polytechnic Inst.—Eng. and Sci. Series, no. 17, Sept. 1927, pp. 1-4, 1 fig.

Method using polarized light, and giving very accurate results, has been developed; two equally stressed tension members are crossed at right angles, and their image projected on screen; if tension in one be changed so it is different from that in other, color will appear in common part; this gives simple method of determining stresses very accurately without necessity of matching colors.

Determination of the Distribution of Internal Tensile Stresses by Photoelastic Means (La détermination photo-élastique de la distribution des tensions intérieures), E. C. Coker. *Technique Moderne*, vol. 20, no. 4, Feb. 15, 1928, pp. 153-162, 37 figs.

Apparatus used optical, and mechanical; application to practical examples tested in tension, such as cement briquettes, buildings, cutting tools; scheme of division of forces at surface of milled piece.

The American Society for Testing Materials —Work During 1927. *Iron and Steel of Can.*, vol. 11, no. 2, Feb. 1928, pp. 59-61.

Brief review of research work of Society; research to bring out new knowledge on properties of metals; effect of temperature on properties of metals; effects of combined corrosion and fatigue; magnetic analysis and testing, project on numbering of steels discontinued.

LABORATORIES. Tests of Certain Materials Interesting to the Sanitary Engineer (Essais de certains matériaux interessant le technicien sanitarie), E. Marcotte. *Arts et Métiers (Paris)*, no. 89, Feb. 1928, pp. 43-54, 8 figs.

Discusses methods and equipments at laboratories dealing especially with resistance of materials to mechanical action and atmospheric conditions; permeability of walls to gas, porosity, hydroscopic characteristics, permeability to water; tests of roofs, pipes, porcelains; effect of frost on stones.

METALS

CORROSION. Metal Corrosion From Liquids, G. A. Luers. *Elec. Traction*, vol. 24, no. 3, Mar. 1928, p. 134.

Convenient table to determine resistance of common metals to corroding liquids; table has been prepared from tests of specimens of metals in contact with liquids as enumerated.

FORGING PROPERTIES. The Behavior of Metals and Alloys During Hot-Forging, W. L. Kent. *Iron and Steel World*, vol. 2, no. 3, Mar. 1928, pp. 171-176.

Investigation of forging properties of metals and alloys was carried out to determine applicability of forging test as measurement of their malleability at high temperatures; results of this investigation suggest interesting conclusions concerning mechanism of hot forging.

MACHINABILITY. Machinability of Metals, O. W. Boston. *Univ. of Mich., Dept. of Eng. Research*, no. 2, Feb. 1928, 38 pp. and (disc.) 38-47, 30 figs.

Methods used to designate machinability; measurement of force on tool; measurement of power or energy required to remove given chip; ability of standardized tool to cut; measurement of fininsh left; penetration of standardized drill; torque developed by drill; cutting speed for certain tool life; hardness numbers; measurement of heat generated and hardness induced. Paper presented at Am. Soc. Steel Treating.

STRENGTH TESTING. Strength Testing of Metal Construction Materials Exhibited at the Berlin Exhibition of Engineering Materials (Die Pruefung der Festigkeitseigenschaften metallischer Baustoffe auf der Werkstoffschau), E. h. Rudeloff. *Giesserei (Duesseldorf)*, vol. 15, nos. 9, 10 and 11, Mar. 2, 9 and 16, 1928, pp. 196-200, 217-225 and 237-245, 58 figs.

Describes machines of different designs for testing static strength; special machines for bending and torsion tests; dynamometers, sclerometers; endurance testing machines; technological tests; abrasion testing. (To be continued.)

The Inner Crystal Structure of Some Native Metals, H. C. H. Carpenter and S. Tamura. *Metal Industry (Lond.)*, vol. 32, no. 13, Mar. 30, 1928, pp. 328-330.

Properties of metals and alloys are properties of component crystals; change of crystal form produces change properties; copper, silver, gold, antimony, bismuth, platinum and meteoric iron studied.

STRUCTURE. The Inner Crystal Structure of Some Native Metals, H. C. H. Carpenter and S. Tamura. *Metal Industry (Lond.)*, vol. 32, no. 13, Mar. 30, 1928, pp. 328-330.

Early investigations; control of crystal structure; form in which native metals occur; native copper; effect of recrystallization. (To be continued.)

TESTING. The Mechanical Testing of Metals, T. F. Russell. *Metal Industry (Lond.)*, vol. 32, no. 14, Apr. 6, 1928, pp. 345-348, 3 figs.

Physical properties of metals including elasticity, limit of elasticity, elastic and plastic deformation, ductility, hardness, toughness, brittleness and malleability, tensile test. (To be continued.)

UPSETTING TESTS. Technical Upsetting Problems (Technische Stauchprobleme), E. Siebel. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 13, Mar. 29, 1928, pp. 403-405, 4 figs.

Abstract of Report, No. 122, of Werkstoffauschusses des Vereins deutscher Eisenhuettenleute, published in full in Archiv fuer das Eisenhuetten (Duesseldorf), Feb. 1928, p. 543.

WEAR TESTING. Abrasion Testing, H. J. French. *Metallurgist (Supp. to Engineer, Lond.)*, Mar. 30, 1928, p. 45.

Review of paper read before Am. Soc. Testing Matls. June, 1927; deals with different methods of wear testing and only incidentally with properties of individual metals; factors which affect results of wear tests, referring principally to two types of testing machine; effect of initial surface condition of metal under test.

X-RAY ANALYSIS—EQUIPMENT. Convenient Movable X-Ray Equipment, A. St. John. *Heat Treating and Forging*, vol. 14, no. 3, Mar. 1928, p. 292.

Castings, welds and metals may be examined where located; lead-enclosed tube is used making lead-lined room unnecessary; rays produce serious physiological effects if they fall on any part of body frequently or for long time.

METALS CUTTING

ROLLED STEEL. Replacing Castings by Steel Elements Cut to Shape by Automatic Shape Cutting Machines, A. Krebs. *Contractors and Engrs. Monthly*, vol. 16, no. 3, Mar. 1928, p. 169, 1 fig.

By cutting various shapes from rolled steel and then welding these together it is possible to form large variety of machine parts and bases economically. (To be continued.)

METALS CUTTING

CHART. Planer or Miller. A Practical Chart (Raboteuse ou fraiseuse, un abaque pratique). *Pratique des Industries Mécaniques (Paris)*, vol. 10, no. 12, Mar. 1928, p. 518, 1 fig.

Method of constructing chart to enable one to see at once if it is more economical to execute metal-working job by planing or by milling.

METAL CUTTING—GAS

UNDER WATER. Cutting Steel Under Water, C. Kandel. *Acetylene Jl.*, vol. 29, no. 9, Mar. 1928, pp. 359-360, 4 figs.

Glenwood Power Station construction project required removal of Lackawanna steel-sheet bulkhead in front of a huge water intake; work consisted of cutting approximately 120 lin. ft. of Lackawanna steel-sheet piling.

METALS, HARD

METALLOGRAPHY. Metallography of Ultra-Hard Metals, K. Schroler. *Metallurgist (Supp. to Engineer, Lond.)*, Mar. 1928, pp. 43-44.

Review of paper published in Zeit. fuer Metalkunde. Jan. 1928; according to author, only way to obtain satisfactory flat surface for subsequent polishing and examination is by grinding on carborundum wheel having soft matrix; concludes that, striking as are properties of ultra-hard materials as now produced, they should be capable of great furthur improvement if they could be produced in sound non-porous condition.

METALS, LIGHT

DILATOMETRY. The Dilatometric Study of Light Metals, M. Haas. *Engineering (Lond.)* vol. 125, no. 3244, Mar. 16, 1928, pp. 337-338, 5 figs.

Dilatometry of pure aluminum, silumin, aluminum-copper alloys and duralumin.

METALLURGY

TERMINOLOGY. Metallurgy. *Metallurgist (Supp. to Engineer, Lond.)*, Mar. 30, 1928, p. 33.

There are many who still think that only those concerned with extraction of metals from ores are truly metallurgists, and that entire modern branch of science dealing with metals after they have left reduction furnace should be called "metallography"; examples drawn from borderland regions serve to show undesirability, even impossibility, of confining term "metallurgy" to its older, narower meaning; and term "metallography" cannot be made to cover wide field opened up by modern growth of science of metals.

MILLING CUTTERS

Milling Cutters, F. B. Heitkamp. *West. Machy. World*, vol. 19, no. 2, Feb. 1928, pp. 69-71, 4 figs.

Selection, care and use of various styles and types of milling cutters which must be chosen to suit particular operation performed; next tooth of cutter should come in contact with work before previous tooth leaves work; cutters must be properly sharpened; life of cutter gang; advantage of milling cutters due to large number of cutting teeth.

STANDARDS. Milling Cutters and Arbors. *Soc. Automotive Engrs.—Jl.*, vol. 22, no. 3, Mar. 1928, p. 321, 1 fig.

Proposed keys and keyways standards submitted for review by industrial users; drawn up by Committee on Milling Cutters; table showing figures for diameter of arbor, nominal width of key, arbor and keyseat, bore and keyway, and arbor and key.

MOLDS (for Castings)

PERMANENT. The Production of Permanent Molds for Cast Iron (Die Herstellung von Dauerformen fuer Eisenguss), K. Lehmann. *Giesserei (Duesseldorf)*, vol. 15, no. 6, Feb. 10, 1928, pp. 130-132, 6 figs.

Discusses Buesselmann molding process and gives number of examples illustrating its advantages.

NICKEL INDUSTRY

Résumé of the Actual State of the Nickel Industry in Canada, United States, and New Caledonia (Résumé de la situation actuelle de l'industrie du nickel au Canada, aux Etats-Unis et en Nouvelle Caledonie, J. Galibourg and R. Contal. *Revue Universelle des Mines (Liège)*, vol. 17, no. 5, Mar. 1, 1928, pp. 233-241.

Metallurgy; treatment of fines and refining of matter; monel metal; malleable nickel nickel of New Caledonia.

NICKEL STEEL

UTILIZATION. Some Applications of Nickel. *Foundry Trade Jl. (Lond.)*, vol. 38, no. 604, Mar. 15, 1928, p. 183.

Review of pamphlet issued by Bureau of Information on Nickel, Ltd.; case-hardened gear steel; new uses for nickel steel; use in locomotive construction.

NONFERROUS ALLOYS

SEGREGATION. Segregation in Nonferrous Alloys, R. Law. *Chem. Eng. and Min. Rev.*, vol. 20, no. 232, Jan. 1928, pp. 135-139, 6 figs.

Greater part of effect due to migration of portion in bulk during period between initial and final stages of solidification; primary reason for such migration is to be sought in contraction of volume experienced by metal in its passage from liquid to solid state.

NONFERROUS CASTINGS

CRYSTALLIZATION. Crystallization in Nonferrous Castings, C. H. Desch. *Metal Industry (Lond.)*, vol. 32, no. 11, Mar. 16, 1928, p. 278.

Author claims it is important in foundry work to investigate peculiarities of crystallization; every casting made consists of aggregate of crystals, so that properties of casting depend not only upon composition, but also upon way in which crystals are arranged; volume change on solidification; viscosity of metals; aluminum in ordinary bronze; brittleness due to heat treatment. Abstract.

NONFERROUS METALS

BIBLIOGRAPHY. Notes on Advances in Nonferrous Metals Research and Industry. *Brit. Nonferrous Metals Research Assn.—Bul.*, no. 22, Mar. 1928, pp. 21-30.

Bibliography covering aluminum and magnesium; copper; brass and bronze; lead, tin, etc.; nickel and cobalt; zinc and cadmium; electrodeposited and other protective coatings; melting, casting and annealing; corrosion and erosion; high-temperature properties of metals; soldering and welding; analyses.

OPEN-HEARTH FURNACES

GAS FLOW. Gas Flow in Open-Hearth Furnaces, K. Feller. *Blast Furnace and Steel Plant*, vol. 16, no. 3, Mar. 1928, pp. 373-375, 1 fig.

Abstract of studies made on flow of gas and gas composition in various types of open-hearth furnaces; conditions of combustion and location of flame; tilting furnace; experiments on models; as result of temperature-variations during gas period composition of gas in port alters as function of preheating temperature.

HEAT LOSSES. Certain Relations Between Refractory Service, Insulation, and the Flow of Heat in the Open-Hearth Furnace, B. M. Larsen and A. Grodner. *Min. and Met. Investigations—Bul.*, no. 32, 20 pp., 12 figs.

Irrespective of how much heat is lost through walls of open hearth, inner surface temperatures must remain about same to make possible given rate of steel production; inner wall and bath temperatures are controlled essentially from within furnace.

TILTING. Open-Hearth Furnaces, A. V. Kemp. *Iron and Coal Trades Rev. (Lond.)*, vol. 116, no. 3132, Mar. 9, 1928, pp. 349 and (disc.) 349-350.

Comparison of tilting and fixed types; better efficiencies and lower production costs with large furnaces; with tilting type, holding capacity is independent of size of tap taken off, because hole is above metal level in normal working position; life of tilting type longer than fixed type; greater production, hence upkeep costs lower; table compares British and Continental furnaces. Paper read before Cleveland Instn. of Engrs.

ACID. A One-ton Acid Open Hearth and Some Experimental Results, C. E. Meissner. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 106, Mar. 1928, 9 pp., 3 figs.

Open hearth built and operated by Chrome Steel Works has been entirely successful; it is true "pilot" furnace, as all results may be duplicated on large-scale operation; results of field tests on alloy steels have proved of invaluable assistance in bettering present products and in opening markets for new products.

BASIC. Rate of Carbon Elimination and Degree of Oxidation of the Metal Bath in basic Open Hearth Practice, A. L. Feild *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 111, Mar. 1928, 17 pp.

Rate of elimination of carbon largely controls time required to make heat of steel by basic open-hearth process and to important degree determines cost of refining; author develops certain equations, derived from established laws of physical chemistry, which will enable this relation between rate of refining and degree of oxidation of metal bath to be computed from operating data.

ONE-TON. One-Ton Acid Open-Hearth Furnace, C. E. Meissner. *Iron Age*, vol. 121, no. 11, Mar. 15, 1928, pp. 731-732, 4 figs.

Experimental results obtained at Chrome Steel works in one-ton acid open-hearth furnace operating under regular conditions; unusually high temperatures available; practical method of deciding upon new alloy-steel analyses; checker chambers increased; melts can be made as high in carbon as desired; furnace oil-fired, using light, low-sulphur oil of 22 deg. Beaume; several ranges of analysis.

OPEN-HEARTH FURNACE PRACTICE

Influence of Different Scrap and Pig-Iron Conditions on the Economy of Open-Hearth Practice (Einfluss verschiedener Schrott-und Roheisenverhaeltnisse auf die Wirtschftlichkeit des Siemens - Martin - Betriebes), G. Bulle. *Stahl u. Eisen (Duesseldorf)*, vol. 48, nos. 11 and 12, Mar. 15 and 22, 1928, pp. 329-338 and 362-370; and (discussion), 371, 4 figs.

Results of investigations, abstracted from report, No. 137, of Steel Works Committee of Verein deutscher Eisenhuettenleute.

OPEN-HEARTH PROCESS

Practice in Making Open-Hearth Steel, C. W. Veach. *Blast Furnace and Steel Plant*, vol. 16, no. 2, Feb. 1928, pp. 258-259.

Suggestions are offered by man of practical experience as to effects of iron oxide, manganese and silicon; charge considered in general.

OXYACETYLENE WELDING

NICHROME SHEETS. Plant Welder Fabricating Nichrome in Sheets. *Can. Machy.*, vol. 39, no. 4, Feb. 23, 1928, p. 30, 3 figs.

Practicability of oxwelding this alloy proved by work done on nichrome sheets for constructing cans for heating gears; heated gears protected by cans while going through furnace; nichrome sheets did not scale, and cans themselves lasted many times life of steel cans that were tried first; inset dished heads, after considerable time, sagged sharply in center and finally broke away.

PICKLING (METALS)

Practical Features of Pickling, W. G. Imhoff, *Iron Trade Rev.*, vol. 82, no. 13, Mar. 29, 1928, pp. 804-806, 2 figs.

Pickling tanks; materials; wood is most common; concrete tanks; many factors involved and various materials employed; heart of timber used; methods for draining tanks; length of tank is determined by length of material to be pickeled; open and closed types; coating of special acid-proof asphalt or acid-proof wash; life of tanks. (Continuation of serial.)

Practical Features of Pickling, W. G. Imhoff. *Iron Trade Rev.*, vol. 82, no. 15, April, 12, 1928, pp. 943-945 and 978, 1 fig.

Design of pickling departments; steel beams, girders, sashes, pipes and rafters; sewers, drains and sump; brick or concrete floors; pickling-tank setting; extremely important to allow plenty of room; black storage area; actual working area; finishing section; steam water and air lines painted; removing fumes. (To be continued.)

PIPE, CAST IRON

MANUFACTURE. New Method of Making Cast Pipe. *Iron Age*, vol. 121, no. 15, Apr. 12, 1928, pp. 999-1003, 6 figs.

Hand labor eliminated in McWane mechanical process; unique multiple-lip ladle pours metal; ladles equipped with 14 spouts; two 6-in. or two 8-in. pipes poured at same time; conveyors and cranes handle materials; plant scheduled like rolling mill; features of continuous operation and flexibility of output; sand handling all done by conveyors; molds and cores handled by cranes.

CENTRIFUGAL CASTING. New Method of Manufacture of Cast Iron Pipe (Nuevo procedimiento para la fabricacion de tubos de hierro fundido), M. Von Anacker. Ingenieria y Construccion, vol. 6, no. 62, Feb. 1928, pp. 87-91, 4 figs.

General description of manufacture of cast iron pipe by centrifugal casting.

PRESSURE VESSELS

CURVED WALLS. Strength of Curved Walls Exposed to External Pressure, C. A. Andsten. *Indus. and Eng. Chem.*, vol. 20, no. 4, Apr. 1928, pp. 364-366, 4 figs.

Method of calculation based upon graphic solution of equations derived by Bach from extensive series of experiments with actual collapse of kind of vessels under consideration; by plotting equations derived from those given by Bach, set of curves is obtained which is of immediate application to design problems; deals with spherical shells and cylindrical vessels.

PYROMETERS, ELECTRIC

Construction and Uses of Electric Temperature-Measuring Instruments (Die elektrischen Temperaturmesser nach Bauart und Anwendung), F. Dettmer. *Berichte der Deutschen KeramischenGesellschaft (Berlin)*, vol. 9, no. 2, Feb. 1928, pp. 83-93, 10 figs.

Classification of pyrometers; description of number of recently developed types; Siemens-Halske, Hartmann u. Braun, Joens & Co., ardometer, etc.

RAILS

MACROSTRUCTURE. Inverse Macrostructure in Certain Makes of Rails (La macrostructure inversée dans certaines fabrications de rails), E. Decherf. *Revue Universelle des Mines (Liége, Belgium)*, vol. 17, no. 6, Mar. 16, 1928, pp. 269-277, 8 figs.

Research on cause of cracks in ingots designed for rail manufacture; rail sections were etched, also tested for hardness; metallographic examination.

MANUFACTURE (KRUPP PRACTICE). The Manufacture of Some Foreign Rails, C. W. Gennet, Jr. *Blast Furnace and Steel Plant*, vol. 16, no. 3, Mar. 1928, pp. 361-367, 3 figs.

Krupp rails from basic open-hearth, bottom-poured ingots of unusual length made for American railroad; roller-straightening method used; figures showing production and consumption of rails in United States; testing and inspection results of recent Krupp rails; two unique departures from American practice that were regular features of Krupp process.

ROLLS, CAST IRON

High Chromium Cast Iron Rolls, J. F. Kayser. Foundry Trade Jl., vol. 38, no. 599, Feb. 9, 1928, p. 94.

For last 20 years, rolls containing as much as 3.5 carbon and 15 per cent chromium have been used to limited extent, and have, in some directions, given exceptionally good results; melting details; slow cooling recommended; final heat treatment.

SAWS (METAL WORKING)

HIGH SPEED STEEL. Development of High Speed Steel Hack Saws or Cutting Off Saws, H. B. Allen. *Am. Soc. Steel Treating—Trans.*, vol. 13 no. 4, Apr. 1928, pp. 603-613, and (discussion) 613-616 and 637, 1 fig.

Discusses application of high speed steel to machine hack-saw blades; steel is shown to be plastic for some time after hardening, even when it is above hardness of 62-C Rockwell; neither does it attain full hardness for considerable time after becoming quite cold; relative performance of saws made of high speed steel and low-tungsten steel is also shown.

ELECTROTHERMAL. Electrothermal Saws (Elektro-Trennmaschinen nach dem elektrothermisch-mechanischen Verfahren), O. Neiss. *Elektrotechnische Zeit.*, vol. 49, no. 3, Jan. 19, 1928, pp. 83-88, 13 figs.

Circular saw for cutting heavy structural-steel sections quickly and cleanly; low-voltage but high-intensity current is passed between blade of saw and metal to be cut; arc formed at cut liquefies metal and hastens cutting speed; saw is combined with unipolar type of dynamo into one unit and is driven by 2000-r. p. m. motor. See brief translated abstract in Elec. World, vol. 91, no. 8, Feb. 25, 1928, p. 418.

SCRAP METAL

SALVAGING. Recovery of nonferrous Scrap. *Iron Age*, vol. 121, no. 10, Mar. 8, 1928, pp. 657-659.

Review of papers presented at Institute of Metals meeting by J. P. Dunlop, T. A. Wright, H. F. Seifert, C. O. Thieme, W. F. Grahan, D. C. Blackmar, E. R. Darby, E. E. Thum, T. D. Stay, D. B. Hobbs and H. O. Burrows; methods of cleaning and smelting waste metals, skimmings and slags from copper brass, bronze and aluminum foundries; collection and segregation of material; production of ingot brass and bronze; remelting secondary aluminum.

SALVAGING—UNITED STATES. Nonferrous Secondary Metals Recovered in the United States, J. P. Dunlop. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 97, Mar. 1928, 10 pp.

Statistical data on recorded recovery of certain classes of secondary metals in 1910-1926, in short tons; recoveries from nonferrous alloys have increased rapidly and will increase further as uses of nonferrous nickel alloys in peace-time manufactures continue to increase.

SCRAP METAL INDUSTRY

Modern Nonferrous Secondary Metal Producer, D. C. Blackmar. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 92, Mar. 1928, 10 pp.

Producers of nonferrous secondary metals are roughly divided into four classes: (1)

large centralized smelters handling but one class of material; (2) large smelters, scrap buyers and sellers, handling anything nonferrous from 5 tons up; (3) large manufacturers who return some of their own scrap but sell considerable tonnage to classes 2 or 4; (4) small dealers who buy and sell in comparatively small quantities, selling mostly to class 2; sources of raw materials.

SCREWS, CAP

MANUFACTURE. Cap Screws Made by New Method, F. L. Prentiss. *Iron Age*, vol. 121, no. 14, Apr. 5, 1928, pp. 936-938, 3 figs.

Recent improvement in processes of making cold-headed cap-screws employed by Cleveland Cap Screw Co.; blank for threading produced by extrusion process; increase of 30 per cent in tensile strength claimed; wire reduced to proper pitch diameter simultaneously with heading; trimmed screws pass through tumbling and lubricating machine; heat treated in electric furnace; passed through quenching machine into rustproofing solution.

SILICON-MANGANESE STEEL

MANUFACTURE. Manufacture of Silicon-Manganese Steel by Electric Furnace (La fabrication du silico-manganese au four électrique), S. Heuland. *Jl. du Four Electrique (Paris)*, vol. 37, no. 3, Mar. 1928, pp. 78-86, 6 figs.

Type of furnace used; cross-section of furnace made of concrete; kind of current and electrodes; mixture used in furnace; method of electrode suspension; principle of mixture calculation, practical manufacturing report.

SOLDERS, CADMIUM

Lead-Tin-Cadmium Solders, C. E. Swartz. *Brass World*, vol. 24, no. 3, Mar. 1928, pp. 74-77.

Study of certain alloys of lead-tin-cadmium system with reference to their use as solders; preparation of alloys for investigation; solidification ranges; lead-tin-cadmium-bismuth alloys; alloys containing zinc; final solidification temperatures; tests of cadmium solders in commercial soldering operations, Paper read at Inst. of Metals.

SPECTRA ANALYSIS

Quantitative Spectrum Analysis, F. Twyman and D. M. Smith. *Am. Inst. Min. and Met. Engrs.—Tech. Pub.*, no. 79, Apr. 1928, 27 pp., 10 figs.

History of development of qualitative spectrum analysis given in U. S. Bur. of Standards—Sci. Paper, no. 444; revival of use attributed to work of W. N. Hartley and A. deGramont; modern quartz spectrograph illustrated and use for quantitative analysis described; specific examples given, chiefly as to impurities in zinc, copper, lead, steels and alloys.

STAINLESS IRON

THERMAL EXPANSION. Thermal Expansion of Alloys of the "Stainless Iron" Type, P. Hidnert and W. T. Sweeney. *U. S. Bureau of Standards—Sci. Paper*, vol. 22, no. 570, Jan. 20, 1928, pp. 639-647, 8 figs.

Results on linear thermal expansion of nine samples of stainless iron; amount of chromium and carbon content; increase in chromium content causes slight increase in temperature at which transformation occurs on heating; average coefficients of expansion given in table; coefficient of expansion increases gradually with temperature.

STAYBOLTS

MANUFACTURE. Staybolt production in railway shops. *Ry. Mech. Engr.*, vol. 102, no. 3, Mar. 1928, pp. 163-167, 9 figs.

Methods and types of machines generally used for manufacture of crown staybolts; manufacture of staybolts on automatic machines; drilling tell-tale holes; two types of crown staybolts are in general use; machining operations required for both types of crownbolts; turning and threading on special-purpose machines; operations on machine; manufacturing on horizontal special-purpose machines. (Conclusion.)

SPECIFICATIONS. United States Government Master Specification for Steel, Staybolt, Boiler. *U. S. Federal Specifications Board—Specification*, no. 550, 3 pp.

Specification for use of departments and independent establishments of Government in purchase of boiler staybolt steel; single grade of material for either solid or hollow staybolts; material and workmanship; requirements; methods of inspection and tests.

STEEL

ANNEALING. The Constitution of Steel and Cast Iron, F. T. Sisco. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 4, Apr. 1928, pp. 659-672, 9 figs.

Deals specifically with structural changes taking place in annealing plain carbon steels and in normalizing and spheroidizing; structural changes taking place are discussed from standpoint of equilibrium conditions and resulting structure is described and illustrated. (Continuation of serial.)

COLD WORKING. The Influence of Cold-Drawing on Mild Steel, R. M. Brown. *Iron and Coal Trades Rev. (Lond.)*, vol. 116, no. 3132, Mar. 9, 1928, p. 341.

Author bases conclusions on research divided into five sections, but says single research can only indicate probabilities; internal stresses due to elastic recovery of material not proportional to work done; cold-drawn steel may be used freely, provided that Izod value is satisfactory. Paper read at Instn. Engrs. and Shipbldrs. in Scotland.

HEAT TREATMENT. Heat Treatments of Various Kinds Discussed at A. S. S. T. Meeting. *Fuels and Furnaces*, vol. 6, no. 3, Mar. 1928, pp. 341-344.

Review of papers presented at meeting of American Society for Steel Treating; selective cooling for adjustment of residual stresses; case nitrification of steel; heat treatment of chromium-nickel steel and of chromium molybdenum steel; heat treating stainless steel; effect of impurities on high speed steels.

HEAT TREATMENT—FAULT LOCATION. Tests in Locating Faults of Treatment, J. D. Gat. *Heat Treating and Forging*, vol. 14, no. 3, Mar. 1928, pp. 274-276.

Temperatures in quenching; nonuniform immersion; steel not suitable for hardening; application of carburization to tests; necessity for checking pyrometers; most usual faults arising in manipulative procedure of hardening are nonuniformity and excessive warpage; determining unhardenable steel.

HEAT TREATMENT—PATENTING. Patenting of Steel, J. S. G. Primrose. *Am. Soc. Steel Treating—Trans.*, vol. 13, no. 4, Apr. 1928, pp. 617-637, 13 figs.

Mechanism and purpose of special form of heat treatment known as "patenting" is explained and different forms of furnaces and heating used are described, from coal-fired "bee-hive" to surface-combustion continuous form; different classes of steel commonly treated for particular purposes; methods of overcoming faults from point of view of physical properties and accompanying microstructure; micrographical details are included of numerous wire specimens examined.

HEAT TREATMENT—PYROMETRIC CONTROL. Pyrometric Regulation of Heat Treating Operations, W. P. Wood. *Fuels and Furnaces*, vol. 6, no. 3, Mar. 1928, pp. 347-350, 2 figs.

Discussion of heat treatment emphasizing importance of obtaining correct furnace temperatures to secure desired metallurgical properties; temperature measurements; thermocouple; use of protecting tubes.

HEAT TREATMENT—QUENCHING. On a New Method of Quenching Steels in a High Temperature Bath, K. Honda and K. Tamaru. *Tohoku Imperial Univ. — Science Reports (Sendai, Japan)*, vol. 17, no. 1, Jan. 1928, pp. 69-83, 7 figs.

Method of obtaining tempered structures by single process without risk of internal failure in steels, which might result during quenching; steels quenched in salt bath heated to high temperatures up to 570 degrees, Cent., and their hardness and microsturcture examined; maximum hardness at quenching temperature of 110 degrees, Cent. (In English.)

HEAT TREATMENT—TEMPERING. Tempering Changes in Carbon Steels, R. Hay and R. Higgins. *Iron and Coal Trades Rev. (Lond.)*, vol. 116, no. 3133, Mar. 16, 1928, pp. 375-376, 7 figs.

Emphasizes importance of time and temperature factors after completion of metallurgical operation of heat treatment; Brinell-hardness test used for preliminary examination; tested also by Charpy tension impact and for tensile strength; results given for different temperatures from which steel was quenched; most interesting feature stated as changes taking place around 650 degrees Cent.

Hardening in Steel by Tempering, T. Matsushita and K. Nagasawa. *Metallurgist (Supp. to Engineer, Lond.)*, Mar. 30, 1928, pp. 36-38, 5 figs.

Review of paper published in Tohoku Imperial Univ.—Sci. Reports, Aug. 6, 1927, tracing effect on magnetic hardness of alterations in tempering temperature and time of treatment of material previously hardened by quenching from above critical range or by application of cold work; emphasizes fact that there are changes in direction in many of property-temperature curves of quenched steels and corresponding changes in magnetic hardness.

RECRYSTALLIZATION. Recrystallization Investigations of Steel for Transformer Plates (Rekristallisationsuntersuchungen an Stahl fuer Transformatorenbleche), M. von Moos, P. Oberhoffer and W. Oertel. *Stahl u. Eisen (Duesseldorf)*, vol. 48, no. 13, Mar. 29, 1928, pp. 393-403, 26 figs.

Review of earlier investigations; recrystallization after cold and hot working; recrystallization diagram; form and nature of carbon in steel for transformer plates.

TEMPERATURE EFFECT. Creep in Five Steels at Different Temperatures, H. J. French, H. C. Cross, and A. A. Peterson. *U. S. Bur. of Standards—Technologic Papers*, vol. 22, no. 362, Jan. 10, 1928, pp. 235-267, 25 figs.

Creep tests in which elongation of metal specimens is observed with time under fixed load; low-carbon structural steel, high-chromium steel, chromium-molybdenum structural steel, high speed steel, and high chromium-high nickel austenitic steel tested; correlated with short-time tension tests at corresponding temperatures; creep charts; relations between stress, temperature, elongation, and time; resistance to oxidation in air.

Behavior of Steel under Prolonged Stress at High Temperatures (Das Verhalten von Stahl gegenueber Dauerbelastungen bei erhoeten Temperaturen), A. Pomp. *Chemische Fabrik (Berlin)*, no. 5, Feb. 1, 1928, pp. 53-54, 4 figs.

Reviews recent work on "creeping" of steel at high temperatures and emphasizes necessity of determining permanent strength of steels for high-pressure work at elevated temperatures; permanent strength defined as lightest load which steel will support at any given temperature without increasing in length after 3 to 6 hr. by more than 0.001 per cent per hr.

TEMPERATURE EFFECT. The Strength of Steel at Elevated Temperatures With Particular Reference to Safety Factors, T. McL. Jasper. *Power*, vol. 67, no. 10, Mar. 6, 1928, pp. 446-447, 4 figs.

Strain value in main cylinder, at unreinforced manways and ordinary dished head; strain values with reinforced manways and elliptical head; ordinary steel used in construction of pressure containers has yield point that is very pronounced; corrosion as factor; stress-time curves for two steels tested at 900 deg. fahr. Abstract of paper read before Am. Petroleum Inst., Dec. 1927.

YIELD POINT. The Yield Point in Steel at Various Temperatures, J. Muir. *Foundry Trade Jl.*, vol. 38, no. 599, Feb. 9, 1928, pp. 91-92, 2 figs.

Describes simple tension experiments made on good quality of steel wire, kept at various temperatures by passing electric current through wire; great increase in rate of extension at yield point, or great increase in mobility produced by even such moderate temperatures as 50 and 100 deg. cent., is no doubt connected with great increase, produced by same temperatures: in rate at which elasticity is restored after overstrain.

STEEL, AUTOMOBILE

MACHINABILITY. The Machinability of Steels in Automobile Construction (Die Bearbeitbarkeit der Konstruktionsstaehle im Automobilbau), G. Schlisinger. *Stahl u. Eisen (Duesseldorf)*, vol. 48, nos. 10 and 11, Mar. 8 and 17, 1928, pp. 307-312 and 338-345, 22 figs.

Determination of best cutting speeds and feeds for machining of case-hardened and high-grade standard steels; comparative investigation with ordinary mild open-hearth steels; influence of water cooling; importance of standardizing alloyed and unalloyed structural steels.

STEEL, MILD

YIELD POINT. On the Yielding of Mild Steel, F. Nakanishi. *Soc. Mech. Engrs.—Jl. (Tokio)*, vol. 31, no. 130, Feb. 1928, pp. 39-49, 11 figs.

Theory that yielding of mild steel is due to shear, does not correspond to maximum stress theory; problem of stability; maximum stress at yield point differs when stress distribution is not similar; by experiments of torsion of hollow bars this fact is ascertained; moment at yield point by torsion must be proportional to moment of area of cross-section; fact agrees very well with experiments.

STEEL FOUNDRIES

Standard Trade Customs for Steel Foundries Defined. *Iron Trade Rev.*, vol. 82, no. 15, Apr. 12, 1928, p. 945.

Code issued by Founders Society of America covers business arrangements with buyers; quotations, terms of payment, handling and marking of patterns, cancellation of orders, claims for errors presented.

STEEL INGOTS

PRODUCTION STATISTICS. Ingot Production Makes New Record. *Iron Age*, vol. 121, no. 15, Apr. 12, 1928, p. 1023, 1 fig.

First quarter well ahead of best preceding quarter; March slightly lower than last year; for first quarter of year calculated output was 12,544,156 tons; both open-hearth and Bessemer tonnage improved in March, compared with February; estimating production in March of electric and crucible steel ingots.

STEEL MANUFACTURE

DEFECTS. Causes for Bloom Croppage Losses, G. D. Johnson. *Blast Furnace and Steel Plant*, vol. 16, no. 3, Mar. 1928, pp. 381-384, 1 fig.

Steel defects discussed as to their sources; difficulties in determination of responsibility; remedies for seams and cracks; steel after blooming is scrapped for two reasons; non-metallic inclusions; locating cause of cracking; blooming-mill practice enters set of conditions causing cracking; question of temperature, both teeming and rolling; tendency for cracking of ingots with unequal sides.

DIRECT PROCESS. Direct Steelmaking Process for the Manufacture of Rustless Steel. *Swedish Export (Stockholm)*, vol. 12, no. 3, Mar. 1928, p. 32.

Plan for making steel direct from iron ore instead of first reducing ore to pig iron; Flodin-Gustafson process; melting briquettes of iron concentrate and charcoal in electric furnace; intimate mixing of finely distributed iron ore with charcoal, shortens reduction process and gives product that can be rolled.

STEEL RESEARCH

Technical Sessions Feature A. S. S. T. Convention at Montreal, W. H. Martin. *Can. Machy.*, vol. 39, no. 4, Feb. 23, 1928, pp. 25-29 and 68, 4 figs.

Review of papers presented at A. Soc. Steel Treating; crystal micrography; case nitrification; locomotive parts failures; X-rays and steel; hardness testing; heat treatment of forgings; high-speed tool steel; fusion welding; types of failure of steel; effect of heat treatment on properties of chromium-molybdenum sheet; test results on chromium-molybdenum sheet of composition suitable for aircraft construction.

STEEL SCRAP

PRICES. Scrap Prices Average Higher. *Iron Age*, vol. 121, no. 15, Apr. 12, 1928, p. 1035, 1 fig.

Average prices of heavy melting steel scrap at Chicago, Pittsburgh and Philadelphia have been higher during first months of 1928 than they were in last three months of preceding year; table of composite prices on iron and steel products; pig iron has shown fair recovery from low levels of November and December; finished steel has been subject to slight fluctuations only, since early 1927.

STRUCTURAL STEEL

PROPERTIES. Factors of Safety and Quality of Material, W. H. Riddlesworth. *Mar. Engr. and Motorship Bldr. (Lond.)*, vol. 51, no. 608, Apr. 1928, p. 152.

Abstract of paper read in Glasgow before Instn. of Engrs. and Shipbldrs. in Scotland.

TESTING. Choice of Test Methods for Acceptance of Structural Steels (Le choix des méthodes d'essai pour la réception des aciers de constructions), C. Fremont. *Génie Civil (Paris)*, vol. 91, no. 12, Mar. 24, 1928, pp. 280-283, 10 figs.

Tensile and impact tests; tests of welded parts; railroad-car axle tests needed.

Structural Steel and Concrete Bars. *Iron Age*, vol. 121, no. 11, Mar. 15, 1928, p. 725, 1 fig.

Replacement of steel by concrete discussed; steel market loss to concrete estimated at over 2,000,000 tons per year; structural shapes not keeping pace with ingots; two independent calculations show results close enough to each other to indicate that fair estimate has been made of extent of that loss; graphic representation of growth in use of concrete bars in buildings and of structural steel in buildings.

HOLLOW BARS. Hollow Steel Bars. *Colliery Guardian (Lond.)*, vol. 136, no. 3503, Feb. 17, 1928, p. 631, 2 figs.

Dunford and Elliot, Sheffield, are pioneer manufacturers in England of steel bars or shafts which are produced with longitudinal hole throughout length of bar, which is of small diameter relative to overall diameter of bar or shaft; material may be described as hollow tubing having abnormally thick walls.

SURFACE COMBUSTION

Some Applications of the Surface-Combustion Process (Einige Verwendungsgebiete des Verfahrens der Overflaechenverbrennung), L. Kovar. *Gas- u. Wasserfach (Munich)*, vol. 71, no. 10, Mar. 10, 1928, pp. 225-229, 5 figs.

Applications of low-pressure and high-pressure surface combustion in furnaces of metal-working shops.

TIN ALLOYS

ALLOTROPY. Allotropic Changes in Tin and Lead Alloys, Travers and Houst. *Metallurgist (Supp. to Engineer, Lond.)*, Feb. 24, 1928, pp. 30-32, 5 figs.

In alloys used in printing industry containing tin, lead and antimony, changes occur even at ordinary temperature; immediately after casting, alloys are harder and

less dense than they are after remaining at room temperature for some time. Abstract translated from Revue de Métallurgie, Sept., 1927.

TIN METALLURGY

Thermic Reduction With Metals of Bolivian Tin Concentrates, C. G. Fink and C. L. Mantell. *Eng. and Min. Jl.*, vol. 125, no. 8, Feb. 25, 1928, pp. 325-328.

Research centered on thermic reduction of tin ores with aluminum; very good separation was made of combined alumina and gangue from heavier liquid tin; reduction of stannic oxide by other metals; avoiding formation of hardhead; effect of iron and bismuth oxides on melting point of stannic oxide.

TOOL STEEL

HEAT TREATING. The Water-hardening of Tool Steels. *Mech. World (Manchester, Eng.)*, vol. 83, no. 2149, Mar. 9, 1928, pp. 164-165, 3 figs.

In heat treating water-hardening tool steel, warping and shrinking of metals are biggest problems; importance of even, slowly rising temperatures and uniform heats; shrinkage; improper annealing; treatment of die; cracking and exploding; two reasons why piece of tool steel may burst in heat treating.

MANUFACTURE. Tool Steel Manufacture. *Colliery Eng.*, vol. 5, no. 47, Jan. 1928, pp. 21-23, 4 figs.

Rock drills, as well as coal cutters, come within category of coal-winning machines, and good deal of interest in being taken in determination of correct grade of steel to use for such purposes; high-frequency melting furnace recently demonstrated at works of Edgar Allen & Co., Ltd., of Sheffield, permits manufacturing in much more closely controlled conditions than have been possible hitherto and hence offers scope for many new developments.

TOOLS, BENDING AND FORMING

Bending and Forming Tools.—2, W. Richards. *Mech. World (Manchester)*, vol. 83, no. 2146, Feb. 17, 1928, pp. 114-115, 7 figs.

In all examples of simple bending tools considered so far work is easily removed after bending operation; cases arise, however, where spring pressure pad or ejector is necessary to facilitate removal of formed work; pressure pads are also employed to locate work, or to hold it in position during bending operation; use of spring pressure pad upon bending tool in connection with bending to U-form of component; bland produced from soft rolled mild-steel strip. (To be continued.)

TOOLS, FORGED

SIMPLIFICATION. Forged Tools. *U. S. Bur. of Standards—Simplified Practice Recommendation*, no. 17, Apr. 1927, 23 pp., 9 figs.

United States Dept. of Commerce recommendations for recognized weights, sizes, and types of forged tools; picks; mattocks; hoes; bars; wedges; blacksmith anvil tools and tongs; sledges and heavy hammers; history of project; summary of general conference.

TOOLS, METAL CUTTING

Small Tools Used in the Railroad Shops. *South. and Southwest. Ry. Club—Proc.*, vol. 19, no. 7, Jan. 1928, 20 pp., 9 figs.

Briefly describes three factors that govern life of metal-cutting tools, namely, design, quality of steel used, and hardening treatment.

TUBES, COPPER, SEAMLESS

Seamless Electrolytic Copper Tubes, J. Silberstein. *Metal Industry (Lond.)*, vol. 32, no. 7, Feb. 17, 1928, pp. 182-183.

New German process developed for manufacturing seamless copper tubes and cylinders electrolytically; characteristic of process is that metallic particles, while being precipitated, are subjected to constant mechanical working, which causes unification of deposit and produces physical properties in resulting material, such as are not obtained by any other electrolytic process.

TUBES, STEEL

HEAT TREATMENT. Changes in Properties of Cold-Drawn Tubes Due to Repeated Stresses and Treatment, F. C. Lea. *Iron and Steel World*, vol. 2, no. 3, Mar. 1928, pp. 169-170.

Behavior under repeated stress of cold-drawn steel tubes indicates that elastic range can be considerably modified by application of repeated stresses as well as by heat treatment; effect of varying degrees of pinch and sink on properties of steel tubes in bright drawn condition. Abstracted from Engineering.

TUBE MILLS, PIERCING

A Newly Constructed Seamless Tube Mill, C. A. Colgate. *Blast Furnace and Steel Plant*, vol. 16, no. 2, Feb. 1928, pp. 240-241 and 248, 2 figs.

Standard Seamless Tube Co. has installed at its Ambridge plant new 51-in. roll-type piercing mill with several innovations in design from conventional-type piercing mill; designed and built by Mesta Machine Co. with Standard Seamless Tube Co. collaborating in design; is largest of its type so far built in United States, if not in world.

ULTRA-VIOLET RAYS

Recent Developments in Ultra-Violet Irradiation, C. A. Cooper. *Discovery*, vol. 9, no. 98, Feb., 1928, pp. 60-62, 4 figs.

Use of "artificial sunlight" for medical purposes led to much research on improved methods, while ultra-violet irradiation also has interesting possibilities in its newest commercial applications; describes burners used and uses of violet rays for body treatment, foods, water and dyes.

WHEELS, STEEL

CASTING. A Southern California Steel Wheel Foundry. *West. Machy. World*, vol. 19, no. 2, Feb. 1928, pp. 81-82, 6 figs.

Foundry methods in producing castings for wheels at plant of Kay-Brunner Steel Casting Co.; conveyor system for running copes and drags from molding machines down line; all work is machine molded; molding of large steel wheels; jolt roll over draw molding machines; pattern storage.

News of the Chapters

STANDING OF THE CHAPTERS

DURING the month of April there were 116 new and reinstated members, while 104 were lost through arrears, resignations and deaths, leaving a net gain for the month of 12 members. The total membership of the Society on May 1, 1928, was 5034. This compares with a total membership on May 1 last year of 4609.

Membership standing of the society as of May 1, 1928, is as follows:

GROUP I		GROUP II		GROUP III	
1. Detroit	479	1. Los Angeles	147	1. New Haven	93
2. Chicago	444	2. Hartford	143	2. Washington	81
3. Pittsburgh	378	3. Dayton	136	3. Tri-City	78
4. Philadelphia	335	4. Milwaukee	122	4. Worcester	76
5. Cleveland	316	5. Golden Gate	122	5. Rockford	65
6. New York	307	6. Lehigh Valley	115	6. Columbus	58
7. Boston	263	7. Canton-Mass.	110	7. Southern Tier	58
		8. St. Louis	108	8. Providence	57
		9. Cincinnati	104	9. Rochester	52
		10. Indianapolis	96	10. Toronto	50
		11. Syracuse	89	11. Schenectady	43
		12. Montreal	77	12. Springfield	41
		13. Buffalo	71	13. Fort Wayne	40
		14. North-West	56	14. Notre Dame	32

GROUP I—The seven chapters maintain the same positions as last month; only 2 of the number however showed gains; Detroit with 5 and Pittsburgh with 1.

GROUP II—Greetings to Los Angeles, the new leader for the month of this group. Hartford has headed this group for a long, long time. Los Angeles a year ago was in position 3 in Group III with 75 members, and practically doubled her membership during the year and transferred from Group III to II. Los Angeles' net gain for the month is 9. This chapter is to be congratulated on the splendid showing and a recent letter received indicates that they have designs on Group I.

Golden Gate and Milwaukee each had a gain of 2 and consequently are still tied for position 4. The other chapters have the same position as occupied on the last month. The three chapters showing the largest gains of this group were Los Angeles 9; Syracuse 4 and Montreal 3.

GROUP III—New Haven still heads the list establishing rather a substantial lead of 12 over its nearest competitor. Tri-City has been giving New Haven quite a little competition for first place. Last month they suffered a reverse of 7 members, which permitted Washington to assume position 2 placing Tri-City 3rd.

Southern Tier with a gain of 1 broke the tie that existed last month between Providence and permitted Southern Tier to go into a tie with Columbus for sixth place. The other chapters remain in the same places as last month.

The present division of the chapters into Groups I, II and III was more or less arbitrarily done on the basis of the possibilities of membership in the centers represented by the chapters. A suggestion has been made that the groupings should be made according to the number of members in the chapter. For example

Group I will include chapters with a membership of	200	or over
II	100	or over
III	60	or over
IV	under 60	

Thus it would be possible when any chapter had a sufficient number of members to transfer from one group to the other automatically. If you have any comments favorable or otherwise we would be glad to receive them.

BUFFALO CHAPTER

The April meeting of the Buffalo chapter consisted of a visit to the plant of the Atlas Steel Corporation, Dunkirk, N. Y., April 27. The party assembled at Hotel Statler, Buffalo, at 1 p. m., motored to Dunkirk and in small groups was guided through the plant on the inspection trip.

Assembling again at 5:30 p. m. the party was guided to the Shorewood Country Club, which is beautifully situated on the shore of Lake Erie, where the Atlas Corporation was host at an elaborate chicken dinner.

F. B. Lounsberry introduced A. F. Dohn, president of the company, who spoke a word of welcome to the chapter. Chairman McCarthy followed by voicing the chapter's thanks and appreciation of Atlas hospitality.

After a short recess, Chairman McCarthy introduced W. H. Wills, the metallurgist of the Atlas Corporation, whose paper, the "Application of Tool Steel" which accompanied by slides proved very interesting and was followed by considerable discussion.

Fifty-two members and guests made the trip and eighteen members of the Atlas organization were also at the dinner. The unanimous opinion of the chapter was that the meeting was the most interesting and enjoyable of the year. The meeting adjourned at 9:30 p. m. *F. L. Weaver.*

CHICAGO CHAPTER

The annual meeting of the Chicago Chapter, held May 10th at the City Club, was attended by approximately 250 members and guests. After dinner the Simmons and Clifford Harmony Girls entertained with excellent musical selections.

R. G. Guthrie, chairman of nominating committee, read his report, and the election of officers followed. The officers elected were:

Chairman—A. M. Steever, metallurgical engineer, Great Lakes Forge Company, Chicago.

Vice-chairman—Donald Colwell, metallurgist, Stewart Die Casting Company, Chicago.

Sec'y-Treas.—J. A. Comstock, assistant metallurgist, Peoples Gas Light & Coke Co., Chicago.

Members of the executive committee: Ray Mau, W. A. Scheuch, Harry Hardwicke, F. R. Jeffries, E. J. Gossett and A. T. Clarage.

The speaker of the evening, R. G. Guthrie, metallurgist, Peoples Gas Light & Coke Company, presented a very excellent paper, the subject being (a) "Effect of Various Gases on Heated Steels." (b) "A Special Method of Carburizing with City Gas."

With the use of lantern slides, Mr. Guthrie exhibited and explained in detail a microscopic investigation of the causes and control of oxidation, decarburization (two different types), carburization, sulphurization, etc. on high and low carbon steels and alloy steels. Considered production of hard and soft spots, blistering and spalling out or pitting, corrosion-resistance, etc He dwelt on different combinations of gases, reversible reactions (such as—decarburizing in a carburizing furnace), and gases liberated by compounds. He outlined methods of treating work and controlling city gas to obtain rapid penetration, at a uniform rate. He discussed the possibility of obtaining various carbon concentrations, extreme case depths in short lengths of time, as well as usual production at minimum time and temperature and cost.

Following Mr. Guthrie's paper, a very interesting discussion ensued. The paper was very well received by all present, everyone feeling that they had gained new knowledge from this subject. *A. M. Steever.*

CLEVELAND CHAPTER

The regular April meeting of the Cleveland Chapter was held in the Cleveland Engineering Society rooms, Carnegie Hall, Friday, April 20, 1928.

Chairman H. H. Smith presided and called upon W. H. White, chairman of the entertainment and program committee, for his report. Mr. White outlined the plans for the second annual outing which will be announced in detail in the May program. The movies taken at the last outing were shown preceding Mr. White's report.

The chairman of the nominating committee, Prof. H. M. Boylston, rendered his report and recommended the following for office during the coming year:

Chairman—D. M. Gurney, The Warner & Swasey Co.
Vice Chairman—W. H. White, The Atlas Steel Corp.
Sec'y-Treasurer—J. S. Ayling, Case Hardening Service Co.
Executive Committee—H. H. Smith, Bourne-Fuller Co.
W. E. Benninghoff, Cleveland Electric Illuminating Co.
W. T. Donkin, Cleveland Wire Spring Co.
E. M. Slaughter, National Acme Co.
A. Jenkin, Case School of Applied Science.

Chairman H. H. Smith then called for further nominations. A motion was made that the nominations be closed and the secretary be instructed to

cast a unanimous ballot for the nominees. The motion was seconded and carried.

At the recommendation of the nominating committee the secretary was instructed to extend a vote of thanks to the retiring officers for the excellent service which they have rendered during the past year.

The speaker, Dr. G. L. Kelley, metallurgist of the Budd Manufacturing Company, gave an extremely interesting talk on metal stamping. This paper covered physical properties of sheet metal, the relation of these properties, especially elongation to deep drawing, the relation of grain size and consideration of the performance of such materials in relation to the dies. The talk was followed by movies of the making of all-steel auto bodies in the Budd plant. Many questions were asked and a lively discussion followed.

This meeting was a joint meeting with the Case School of Applied Science Group of the American Society for Steel Treating.

Attendance at the meeting was about 200 while the dinner preceding was again well attended by about 50 members and guests.

J. S. Ayling.

DAYTON CHAPTER

The regular monthly meeting of the Dayton Chapter was held Monday evening, April 16, at the Engineer's Club. Twenty-five members met for dinner after which they listened to a brief but interesting talk on Golf and Golf Clubs by J. C. Gilbert of the Crawford, MacGregor and Canby Co., of Dayton, one of the oldest and best known manufacturers of golf equipment in this country. Mr. Gilbert traced the evolution of the golf club and gave his audience much information about the materials used in the manufacture of golf equipment and the care necessary in producing a first class club.

Sixty members and guests assembled at 8:15 p. m. in the main auditorium for the regular meeting. George J. Oswald, metallurgist for the National Cash Register Co., gave the educational feature; an illustrated description of troostite and sorbite; the two metallographic constituents in hardened and tempered steels.

The principal speaker of the evening was E. H. Dix, Jr., research metallurgist of the Aluminum Company of America, who lectured on "Aluminum and Aluminum Alloys". Mr. Dix's talk was divided into three parts. In the first he discussed the various alloys of aluminum and how they were made. Included in this discussion was a brief summary of the properties and characteristics of the sand-cast, die-cast and wrought aluminum-copper, aluminum-copper-silicon and the aluminum-silicon-magnesium alloys. Mr. Dix gave an interesting account, illustrated by slides, of Alclad, the new aluminum-coated alloy sheet, and outlined the commercial uses to which this sheet is being put.

The second part of the talk was an illustrated elementary discussion of the theory of heat treatment of aluminum alloys.

The third part of the lecture took up the commercial uses of aluminum alloys. This was illustrated by slides showing some of the unusual ways in which the light alloys of aluminum are used. The application of these

alloys to the aircraft and automotive industry is well known. Not so well known, however, is the use of aluminum for crankcases of Diesel engines, some of which weigh 3500 pounds; for motor bus, street car and railway coach construction in which heat treated alloys are now being used for structural members as well as for body construction.

The discussion which followed the talk lasted until a late hour.

F. T. Sisco.

GOLDEN GATE CHAPTER

On Wednesday evening, April 18, Golden Gate Chapter again had the privilege of holding their meeting at Stanford University, Palo Alto. A splendid dinner was served at Stanford Union at 6:30 p. m. to about 150 members and guests. Guides were assigned to small groups of six or eight people who led them on a tour of the shops and laboratories, which were in operation.

We enjoyed seeing the splendid equipment available to these men in preparing themselves for the next war, particularly the scientific instruments for determining the range for anti-aircraft guns. There were many other things of interest such as various heat indication instruments, furnaces, the foundry, the microscopes, air compressors, testing of an internal combusion engine, refining of crude oil and others too numerous to mention.

Of particular interest was the "tunnel" in which airplane propellers are tested to determine the proper pitch of the blade of a propeller to obtain a certain "pull", etc.

After the tour we assembled in the Geology building to listen to the speakers of the evening.

Preceding the lectures the usual method was used in disposing of two books which was taken care of by our chairman, Dr. Welton Crook.

The first speaker, Dean Hoover, had for his subject "History of the Development of the Use of Metals". "During the last few decades," Dean Hoover said, "remarkable strides have been made in the use of all metals." The line representing tonnage produced is almost perpendicular, with 1,000,000,000 pounds produced during 1927.

Prof. Domonoske was the second speaker and his subject was "Relation between Cutting Power of Metals and their Heat Treatment". He mentioned various tests that had been made, particularly Taylor's test. Another test that was mentioned was one that took six months to conduct and cost approximately $200,000. "It was not long ago that tests were run on a five horse power machine," said Prof. Domonoske. "Now they are using a fifty horse power machine and in the near future they expect to use one hundred horse power machines."

Dr. Crook, in behalf of Golden Gate Chapter, thanked Prof. Domonoske particularly for the splendid way in which he had arranged the visit to Stanford University, after which the meeting adjourned.

F. E. Peterson.

HARTFORD CHAPTER

On Tuesday, April 10, the Hartford Chapter held its regular monthly

meeting in the Hartford Electric Light Company's auditorium with E. C. Smith, assistant general superintendent of the Central Alloy Steel Company of Massillon, Ohio, as the speaker.

Mr. Smith described the production and application of alloy steels for the automotive industry. His paper was quite brief but gave an opportunity for about an hour and three quarters discussion which was freely entered into by all present. Mr. Smith spoke in practical every day terms which were very pleasing to his audience. He described the numerous applications of steel with particular reference to those for the Ford Motor Company giving various analyses of their uses.

Preceding Mr. Smith's talk, Charles F. Hathaway, foreman of the small tool works heat treating department of the Pratt & Whitney Company gave the practical talk of the evening. Mr. Hathaway extended his remarks into a little greater detail than some of the previous speakers and his comments caused a great deal of merriment among those attending. Mr. Hathaway radiates frankness in all of his talks and his example ought to be followed by a great many speakers.

At the conclusion of his remarks which took up about half an hour he stated that some day he would come up and give the chapter a real talk. The program committee has made note of this.

Preparations are under way for the annual banquet which will be held in June and promises to be the largest Steel Treaters event in Hartford since the Spring Convention in 1926. Further announcements will follow during May for the banquet. *Richard Stanton.*

LOS ANGELES CHAPTER

The regular April meeting of the Los Angeles Chapter of the A. S. S. T. was held Thursday evening, April 12, at the regular place, and at the usual time.

The excellent dinner, which was first on the program was made more enjoyable by some lively entertainment. There were ninety members and guests present at dinner.

Immediately following the dinner, the nominating committee made its report to the chapter. It has been very noticeable during the past year that all committees and all members of the chapter, who have been delegated with special duties, have worked with a determination to make their efforts of real service to the chapter. It was evident that the nominating committee, headed by Earl Jorgenson, has given much thought as to the men who are to have charge of the next year's activities of the Los Angeles Chapter.

Wade Hampton, Chairman, appointed an auditing committee to meet with the treasurer about the first of May.

Bill Lowry of Axelson Machine Company, made a very enthusiastic and detailed report on the activities of his committee. We all owe Bill a great deal because of his good work to the chapter.

Immediately following the reports of the committee chairmen, we were most agreeably surprised by Ralph Hall, extending an invitation to the chapter to attend another barbecue at Ventura. Remembering our last

year's trip to Ventura, the members accepted the invitation very eagerly. The date will be determined later.

We had as our main speaker W. T. Morin of the Pacific Abrasive Company. He had with him a 5-reel picture on high temperature refractories made by the Carborundum Company at Niagara Falls. The picture was unusually good and following its showing Mr. Morin gave a short talk on the subject. The evening was an interesting one and there were again several new membership applications handed to the secretary, which should help the Los Angeles Chapter maintain its remarkable stride. *H. V. Ruth.*

PHILADELPHIA CHAPTER

The Philadelphia Chapter has had two meetings during the month of April. The first was a plant inspection meeting held at Chester, Pa. Two plants were visited by about ninety members and guests of the chapter. The first was the blast furnaces of the Delaware River Steel Co. and the second the A. H. Wirz, Inc., manufacturers of collapsible tubes. Following the plant inspections, which occupied the entire afternoon, a dinner was served at the Chester Club, after which a splendidly illustrated lecture, using moving pictures, was given by Charles Hart, president of the Delaware River Steel Co. This meeting was tremendously successful from every standpoint.

The second meeting for the month was held at the Engineers' Club, in Philadelphia on Friday evening, April 27. This was the regular monthly meeting of the chapter.

The regular business of the meeting included a report of the nominating committee in accordance with the new by-laws of the chapter and those of the National Society. The nominees for the several chapter offices were announced as follows: For chairman, Dr. R. H. Patch of the E. F. Houghton & Co.; for vice-chairman, H. E. Allen, Henry Disston & Sons Co., Inc.; for secretary-treasurer, A. W. F. Green, The John Illingworth Steel Co.; for directors, four to be elected: Messrs. F. R. McCrudden, National Lock Washer Co.; Norman C. Einwechter, Einwechter & Wyeth; M. M. Kennedy, Navy Yard; Dr. H. C. Boynton, John Roebling's Sons Co., Trenton, N. J.; C. C. Willits, Central Alloy Steel Corp.; and John Harsch, Leeds & Northrup Co.

The first speaker of the evening was Dr. Victor O. Homerberg who chose for his topic the subject of Nitralloy. Dr. Homerberg illustrated his talk with a number of lantern slides, which because of their clarity and direct bearing on the immediate discourse for which they were intended, made his talk tremendously interesting.

Dr. Homerberg explained first of all the selection of alloys found to be most adapted to the process of nitrogenizing. By the process of elimination it was shown that the chromium-molybdenum-aluminum series of steels was the best.

The speaker then discussed some of the metallurgical procedures being followed for the production of the steel which is to be submitted to the nitriding process. One of the interesting features of this part of his talk was the fact that the aluminum is introduced into the metal in the

form of ferroaluminum and in a granular condition. Inasmuch as the amount of aluminum present in the resultant steel is approximately one per cent, and is in a solid solution state, this proved very interesting.

There was considerable explanation of the physical properties of the steels used in the process and Dr. Homerberg particularly stressed the importance of the impact test, paying particular attention to the mechanism of that type of test.

His description of the actual process for introducing the element nitrogen into the surface of the steel was especially lucid and understandable.

The second talk for the evening was a practical discourse entitled Carburizing Practice, by E. H. MacInnis, assistant chairman of research of the E. F. Houghton Co.

Mr. MacInnis drew from a vast knowledge to explain the pros and cons of the carburizing process. His discussion had to do with general practices, selections of materials, including steel, pots, compounds, and furnaces.

Arthur W. F. Green.

PITTSBURGH CHAPTER

The Pittsburgh Chapter held its May meeting on the evening of the third in the U. S. Bureau of Mines Building. A goodly number of the members attended the dinner which was served preceding the meeting. At 7:30 p. m. motion pictures of wild animal and plant life were shown in the auditorium.

At 8 p. m. Chairman James P. Gill called the meeting to order and, after the usual business session, invited the newly elected officers to assume their duties.

The following are the Chapter's officers for the ensuing year: W. I. McInerney, chairman, G. M. Eaton, vice chairman, H. L. Walker, sec'y-treas.

The executive committee is as follows: D. J. Richards, Professor James Aston, A. D. Beeken, Jr., D. H. Horne, H. M. German, E. H. Dix, Jr., J. A. Succop; Prof. S. L. Goodale; W. B. Crowe, A. M. Cox, J. P. Gill, W. J. Merten.

Chairman McInerney then took the chair and after announcing his committee chairmanship appointments, welcomed Dr. V. N. Krivobok of the Carnegie Institute of Technology as the speaker of the evening.

The topic of the address was "Some New Observations Concerning Properties and Structure of Special Steels."

It was brought out and demonstrated that cold working, followed by moderate heating, of austenitic special steels results in a very noticeable change in mechanical properties (mostly hardness), the degree of increase depending on the temperature of heating and the time at the temperature. The temperatures producing the increase in hardness are much higher than the so-called "blue range" temperatures of plain carbon steels; for instance, heating to 1000 degrees Fahrenheit almost trebled the hardness of manganese steels obtained on cold working. Still higher temperatures—up to 1400 degrees Fahrenheit, do not seem to increase the hardness, neither do they have a softening effect; the hardness obtained through cold working remains practically unchanged.

This discussion was accompanied by a thorough study of the structures

of steels, resulting from heat treating in various ways of these steels with and without cold work.

The general conclusion summarized by the speaker at the close of the address can be simplified as follows:

1. Our notion of certain steels being "austenitic" because of the presence of large amounts of special elements are false.

2. These steels are merely in a metastable condition and by suitable treatment undergo much the same transformations as plain carbon steels.

3. Cold working has a very definite effect on the structure of these steels.

4. The effect of cold work is preserved at temperatures as high as 1400-1500 degrees Fahrenheit.

5. The solubility of carbides in gamma iron is much affected by the strain.

The speaker dealt mostly with manganese steels yet was quite emphatic in that the same phenomenon, with certain reservations and modifications, applies also to other steels.

A general discussion of the theory of hardening based on the speaker's observations followed the more specific first part of the talk.

Harry A. Neeb, Jr.

RHODE ISLAND CHAPTER

The April meeting of the Rhode Island Chapter of the A. S. S. T. was held on the 18th, in the new rooms of the Providence Engineering Society.

The lecturer, Dr. V. O. Homerberg, consulting metallographist of the Massachusetts Institute of Technology, and quite a few of the members attended the dinner preceding the meeting.

Prof. Homerberg gave a very interesting talk on "Case Hardening with Ammonia" and cited the history of the process, describing the steels used, together with their corresponding physical properties.

He also told of many instances where the nitrided steels were being used with good success and stated that this process of nitriding has great possibilities.

The lecture was illustrated by stereopticon and was well received by the 65 members and guests present. *E. G. Peterson.*

Arthur H. Annan, past chairman of the Rhode Island Chapter and for many years a member of the executive committee, died at his home in Providence recently at the age of 63 years. Mr. Annan was for 35 years with the Rhode Island Tool Company of Providence and recently its superintendent.

ROCHESTER CHAPTER

Sam Tour, chief metallurgist of the Doehler Die Casting Company, Batavia, N. Y., addressed the Rochester Chapter at their regular meeting on April 9, the subject of his talk being "Die Castings".

Eighty-nine members and guests attended the meeting while twenty-six were present at the dinner. It was the largest gathering of the year.

Mr. Tour overcame a handicap at the beginning of his talk, due to a

temporary failure of the stereopticon. There were a number of interesting slides, showing the history and mechanism of die casting as well as some results now obtained. These illustrations were supplemented by an interesting exhibit of miscellaneous die-cast parts, some of them being remarkable examples of the art.

Some of the important problems that have been experienced and partly overcome are: selection of suitable alloys which must have ductility when hot and sufficient strength when cold; improvements in die steel has to be taken into consideration which will stand up under casting temperatures and the chemical action of the molten alloys. Some very ingenious molds have been devised such as in casting spiral fan housings and Ciné Kodak frames.

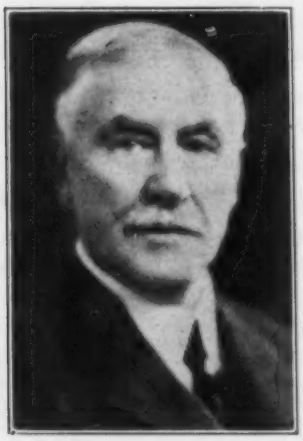
Some of the best known compositions of aluminum and zinc bases were discussed. Durable zinc-base alloys are being quite extensively used on small gears, etc. Due to the technical knowledge and experience required it is always best to rely on the judgment of the die caster as far as the exact choice of the alloy is concerned. He should be also consulted on the design of the casting and furnish all possible data regarding its intended application.

Mr. Tour was very generous in his exchange of technical information although there were secrets of the trade which he did not feel at liberty to give.

Following a very lively discussion the meeting adjourned with a rising vote of thanks for the speaker.

H. J. LeClaire.

The Rochester Chapter of the A. S. S. T. takes pride in having as one of its members perhaps the oldest living active member of the Society. He is a man who has had broad experiences in life and one who can and does lend his wonderful personality in executive committee meetings of the chapter as well as in the regular monthly meetings. We take pleasure in introducing to the entire membership of the Society, Mr. F. W. Arvine. And in order that we might be acquainted with a few of Mr. Arvine's accomplishments, we have gathered together an abbreviated biography.



F. W. Arvine

During the Civil War (when Mr. Arvine was about 16 years old) he worked as a machinist in a gun factory. Being a born inventor, he bent himself in the line of mechanical inventions, his first being the invention of a patent skate in which the runner acted as a lever to tighten the straps. Later he engaged himself in the electrotyping business. As a development from the electrotyping business, he became interested in the making of steel dies for the purpose of duplicating costly pieces of foreign styles of jewelry. This work involved the various processes of heat treating. The develop-

ment was highly successful and was patented, with rights being sold to many in the U. S. and Europe.

Mr. Arvine next worked with a scientific school in the preparing of models of mechanical movements. He invented and developed a pantograph mechanism for enlarging or reducing drawings.

Later, he became the superintendent of a chemical works producing bromine. After some years his activities were diverted to the study of the lubrication of railway equipment which led him into the petroleum industry. He spent much of his time in this line of endeavor developing, inventing and otherwise aiding in the up-building of the huge oil industry.

As a result of his experience in the oil industry he was frequently called upon as a witness regarding infringement of patents and for some ten years or more spent much of his time as an expert witness. This led to investigations in mining projects in Canada through which he became interested in several large steel works where his interest in the subject of steel was very much augmented.

Having large holdings of property in the city of Rochester, he has spent his late years in this city and has been an ardent and enthusiastic member of that chapter of the society for the past five years as well as being a member of the executive committee of the chapter for the entire five years.

SPRINGFIELD CHAPTER

The meeting of the Springfield Chapter was held Monday, May 7, at the Chamber of Commerce. Mr. Stricker, consulting chemist and metallurgist introduced the speaker, Dr. V. O. Homerberg, professor of metallography, Massachusetts Institute of Technology.

Dr. Homerberg's subject was "Nitralloy and the Nitriding Process," which he presented in considerable detail. He first described the various steels which this nitriding process had been tried upon, then explained that the results of this research work had finally adopted that group of alloy steels containing aluminum, aluminum and chromium, aluminum, chromium and molybdenum, with varying amounts of carbon.

The nitriding process consists of case hardening the above class of steels at a temperature of 900 to 950 degrees Fahr. with ammonia. The ammonia is passed through lime to remove moisture, then to the chamber where the steel parts are to be cased. The ammonia breaks down into nitrogen and hydrogen, the nitrogen penetrating the outer surface of the metal forming a solid solution with the metal producing a very hard case.

No further heat treatment is required after case hardening with nitrogen. One necessary feature, however, is that all strains should be removed from the metal before nitriding, otherwise, excessive grain growth may result.

The depth of case varies with the time and temperature. It is claimed that a case of 1/32 inch may be obtained in 24 hours. This nitrogen case is extremely hard, and with special instruments has been recorded as equivalent to 1000 Brinell.

For protection of parts against nitriding it was found that a coating of

tin would give satisfactory results. Even though the tin would be burned away at the nitriding temperature, tests proved that the nitrogen did not penetrate the tinned portion.

The applications of nitriding were pointed out to be many and varied; in metal to metal wear such as encountered in valve stems, resistance to corrosion other than acids, ability to withstand elevated temperature and pressure, etc.

Following Dr. Homerberg's address considerable discussion ensued regarding the relative merits of nitralloy and other metals. The meeting was exceptionally interesting and educational. *Tracy C. Kerr.*

ST. LOUIS CHAPTER

The regular monthly meeting of the St. Louis Chapter was held on Friday evening April 20, 1928, at the American Hotel Annex. The meeting was preceded by an executive committee meeting which appointed a nominating committee consisting of G. Froelich, Atlas Tack Corporation as chairman assisted by L. T. Clarke, Leschen Rope Co., and A. W. Grosvenor, Laclede Steel Company. After the usual get-together dinner a short business meeting was held at which time John F. Keller, steel specialist of the Engineering Extension Department of Purdue University, Lafeyette, Indiana, was introduced. The subject being steel and its treatment, was illustrated on the blackboard and demonstated by electricity on a piano wire as only Mr. Keller can.

It is to be regretted that after the untiring efforts of the officers to bring this type of talent to the chapter, that only sixty-eight members were present to a most interesting educational and entertaining demonstration of the critical points of steel. We are indeed indebted to men of Mr. Keller's type who devote their time in giving instructions in the proper methods of handling steel. All in all it was a very successful meeting, and a lively discussion followed after Mr. Keller's demonstration the meeting was adjourned with a rising vote of thanks to him. *Carl G. Werscheid.*

SYRACUSE CHAPTER

The regular monthly meeting was held on April 10 in the Chamber of Commerce Building. At eight o'clock the meeting was called to order and without delay Chairman Frazer introduced as the speaker of the evening W. H. Kildow, Jr., connected with the engineering department of the National Machinery Company, Tiffin, Ohio.

Mr. Kildow, whose subject was "Deep Piercing of Forgings," presented first, two reels of motion pictures showing the forging machines in operation on hot piercing and upsetting, following next with a simple description of the apparatus and its operation, and finally inviting questions and discussion.

It developed that the machine owes its success in no small measure to the long life of the piercer tools. The dies and tools are so designed that there is nothing but a parting of the metal by the piercer and positively no extrusion, otherwise the wear would be excessive. Another feature

was the simplicity and speed of operation. The main problem in quantity production with this machine is to get sufficient furnace capacity to heat the forging bars fast enough. The extremely small waste in making deep pierced forgings gives this process an advantage over drop forging with its flashings and croppings. It is also claimed for this method that holes may be pierced seven and one-half times the diameter with the accuracy of a drill press, and that the forgings will be second to none in quality and appearance. The forged articles illustrated were socket wrenches, drag links, gear trains, differential pinions and flanged sleeves.

S. Peskowitz.

TRI-CITY CHAPTER

The regular monthly dinner meeting of the Tri-City Chapter of the American Society for Steel Treating, was held Tuesday evening, April 24, and was attended by sixty-five members and friends. The meeting was held at the Davenport Chamber of Commerce Building, Davenport, Iowa.

Dr. N. B. Hoffman, chief metallurgist for the Colonial Steel Company of Pittsburgh, was the principal speaker of the evening. Dr. Hoffman's talk covered some of the more important phases and terms used in metallurgical work. He described the various methods of heat treating plain carbon and high speed steels and likewise showed with photomierographic slides the change in the physical structure of the steels during the treatment.

Business conducted during the evening was the election of officers and directors for the chapter for the coming year. Those elected were:

Chairman—George A. Uhlmeyer, industrial engineer, Peoples Power Company.
Vice-Chairman—R. E. McGee, metallurgist, International Harvester Co., Rock Island, Illinois.
Sec'y-Treas.—Ernest E. Mueller, representative Carpenter Steel Company.
Executive Committee:

Earl Taylor, Yellow Sleeve Valve Engine Works, East Moline, Ill.
E. H. Sohner, International Harvester Co., Rock Island, Ill.
P. J. Barry, Barry Co., Muscatine, Iowa.
Prof. John Fielding, University of Iowa, Iowa City, Iowa.
Fred Turner, Walworth Mfg. Co., Kewanee, Ill.
Hyman Bornstein, Deere & Co., Moline, Ill.
W. H. Hull, John Deere Harvester Works, East Moline, Ill.
E. E. Einfeldt, French & Hecht Co., Davenport, Iowa.

G. A. Uhlmeyer.

WASHINGTON-BALTIMORE CHAPTER

On April 21st an unusually well attended dinner and meeting was held at the Southern Hotel. About 60 persons were at the dinner and many more came in afterwards. About twenty motored over from Washington. All were well rewarded for their efforts by the interesting talk given by A. H. d'Arcambal of the Pratt & Whitney Company, who spoke on the heat treatment of small tools.

The speaker laid down three principal factors: 1. design of tool; 2, quality

of steel; 3, hardening treatment. To this he added a 4th factor more recently discovered and not understood. This was finish.

It had been found that a lapped finish gives longer life than the usual ground finish. It was suggested that this might be due to removing a soft skin or a cold working effect. Numerous cases were cited illustrating the three cardinal points.

The speaker stated, that formerly his company purchased all steels by brand. Today all material is bought to rigid specifications including chemical analysis, hardness, microstructure, and deep acid etch. As a result they have very few rejections and have cut machining costs and hardening losses to less than one half of one per cent.

The speaker seemed to prefer the 1.10 to 1.20 per cent carbon steels for all purposes except a few special cases and of course where high speed steel was required, for which he preferred the 17 per cent tungsten type. Well-made electric steel was considered superior to crucible steel.

Under the third factor the speaker brought out the very great changes that have taken place in the attitude toward the hardening room. This has been possible largely because of the almost complete change over to electric heating automatically controlled and modern pyrometric methods of temperature measurement. There is no reason why the hardening room should not be as pleasant a place as any other part of the plant. Green window glass is used to aid the high speed steel treater to better judge his work.

The speaker had with him a large collection of special types of small tools illustrating the character of the work and interesting types of failures.

The full and detailed discussion that followed the talk emphasized the great interest of the audience and their appreciation of the able manner in which the data was presented. *J. R. Freeman, Jr.*

VOLUME XIII COMPLETED

THIS issue of TRANSACTIONS completes Volume XIII which covers the period from January, 1928, through June, 1928. Volume XIV will include the period from July, 1928, through December, 1928. The index for Volume XIII is now ready for distribution and may be secured upon request.

Those desiring to have their loose copies of Volume XIII bound in accordance with the style used in binding Volumes I to XII inclusive, may do so by forwarding them to the executive office of the society, 7016 Euclid Avenue, Cleveland, together with $2.00 per volume and they will be bound and returned promptly.

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WHEN success comes from doing something that has not been done before, there are two kinds of knockers, those who will say it can't be done, and those who make cheap imitations. This is true in any field of art or invention.

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A few knockers still say it can't be done. Others make imitations whose cheapness discloses their failure. As imitators they have not even learned that unrefined, unfused mixtures cannot give the chemical and physical characteristics necessary for a neutral constant bath that will not deteriorate or attack the work or container.

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